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Exploring Elementary Students' Difficulties in Understanding the Concept of Density: A Comprehensive Review Analysis

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ABSTRACT

Density is a difficult concept for children (and beyond) to understand. This article is a comprehensive literature review of research over the last half century on the difficulty of primary school students to understand the concept of density. The most difficulties and misconceptions of students arising from the relevant research are presented. This literature review aims to help those researchers who are concerned with students' understanding of the concept of density by providing them with a comprehensive overview of the research data on the subject to date.

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1. INTRODUCTION

Students' understanding of density has been widely investigated across educational levels, from preschool to university. Many reports regarding this matter have been well-documented (Kohn & Landau, 1987; Kohn, 1993; Harrell & Subramaniam, 2014; Zoupidis *et al*., 2016, Zoupidis *et al*., 2021). One of the difficult subjects is science, making many researchers focus on this subject, especially how to teach and the learning process to get a better understanding.

In Science, Research consistently indicates that density is a difficult concept for both elementary and middle school students to grasp (Smith *et al*., 1985; Hewson & Hewson, 1986; Kohn, 1993; Dawkins *et al*., 2008; Zoupidis *et al*., 2011; Xu & Clarke, 2012; Zoupidis *et al*., 2016; Zenger & Bitzenbauer, 2022). This difficulty arises because density is abstract (Borreguero *et al*., 2018) and requires the simultaneous consideration of mass and volume as an intensive property (Hitt, 2005). Its non- obvious nature means it is relational and inferred rather than directly observed.

Despite the ability to understand mass and volume separately, many students fail to develop a conceptual understanding of density (Hitt, 2005). While some studies suggest children can form intuitive perceptions of matter's properties, including density, when given rich learning experiences before formal education (Klopfer *et al*., 1992; Dawkins *et al*., 2008), these rarely develop into scientifically accurate concepts without targeted instructional interventions (Ginn & Watters, 1995; Rice, 2005; Lederman & Lederman, 2015). Without such support, misconceptions persist into high school and even university education.

The relevance of studying density in science education lies in its foundational role for understanding other physical phenomena, such as buoyancy and material properties. Misconceptions in this domain can impede the acquisition of more complex scientific ideas. Therefore, a systematic review of research addressing elementary students' difficulties in understanding density is necessary to inform effective teaching strategies, curriculum design, and teacher professional development.

The purpose of this paper is to synthesize the literature over the last five decades to identify persistent misconceptions, examine their origins, and propose educational implications. Its novelty lies in integrating conceptual, procedural, linguistic, and representational perspectives into one comprehensive framework, with the expected impact of guiding more effective instruction and improving students' long-term scientific literacy.

2. METHODS

Table 1 presents the list of keywords and key phrases used in the literature search. This methodological design follows a deliberate and systematic literature review to ensure that the issues under investigation were assessed in a clear, understandable, and transparent way. The review covered studies published between January 1974 and August 2024, providing a fifty-year overview of research on density-related learning difficulties. The literature search was conducted over two months, from July to August 2024, ending when the last relevant citation was identified.

The review employed a hierarchical search strategy across Google Scholar and several international databases, including ScienceDirect, Scientific Electronic Library Online (SciELO), and Taylor & Francis, supplemented by reference tracing from prior works. Two sets of search terms (one focusing on the scientific concept of density and the other on learning-related aspects) were applied in both English and Greek. Non-English and non-Greek studies were excluded. Inclusion criteria required that studies address primary or early secondary students, include a detailed account of research questions, methods, data collection tools, and findings, and be published in peer-reviewed journals. Exclusion criteria removed studies on older students, insufficient methodological detail, and non-peer-reviewed sources.

Table 1. Keywords or key phrases used in the literature search.

Terms Related to The Scientific Concept	Operator	Terms Consistent With Learning
(“Density” OR “The concept of density” OR “Density in science’’ OR “Science education density” OR “Experiments of density” OR “Understanding density”)	AND	(“student»/ «pupil”/ “K-12 student” OR “child”/ “children’’ OR “learning” OR “student outcome” OR “teaching” OR “intervention” OR “educational” OR “school” OR “primary/ elementary education’’ OR “teaching learning sequence” OR “misconceptions” OR “alternative ideas/conceptions” OR “intuitive theories” OR “difficulties in understanding”)

3. RESULTS AND DISCUSSION

3.1. Misconceptions and Conceptual Barriers in Understanding Density

Table 1 has already outlined the systematic approach for identifying relevant literature, and from this dataset, a range of recurring misconceptions among elementary students has been identified. A prominent finding across studies is that students frequently confuse density with weight or mass, assuming that heavier objects must have greater density and lighter objects must have lower density (Smith *et al*., 1997; Zenger & Bitzenbauer, 2022). This misconception is persistent because weight is more perceptually accessible (students can feel it), whereas density is an abstract, calculated property (Fassoulopoulos *et al*., 2003). Moreover, the distinction between mass and weight is rarely well established before the age of mid-adolescence, leading to compounded misunderstandings when introducing density as a ratio of mass to volume.

Another widely reported misconception is that density depends on the amount of material rather than being independent of quantity (Klopfer, 1992; Zoupidis *et al*., 2016). Students often treat density as an extensive property, influenced by the size or volume of the object, because they have difficulty conceptualizing it as an intensive property. This results in incorrect reasoning patterns such as “if you cut an object in half, it will have less density” or “larger objects sink more easily because they are heavier.” Such statements indicate that students fail to recognize the relational nature of density and instead interpret it as a singular characteristic related only to one variable (mass or volume), depending on context (Harrell & Subramaniam, 2014).

3.2. Influence of Prior Knowledge and Floating/Sinking Frameworks

Research shows that young learners often begin their encounters with density through everyday experiences of floating and sinking phenomena. These are familiar and engaging contexts, yet they can reinforce misleading reasoning. Students might predict whether an object will float or sink based solely on its weight or size, without considering the comparative densities of the object and the fluid (Perkins & Grotzer, 2005; Zoupidis *et al*., 2016). For example, if two objects of similar size behave differently in water, many students attribute this to hidden cavities or shape differences rather than differences in material density (Smith *et al*., 1992).

Many researchers (Smith *et al*., 1992; Kawasaki *et al*., 2004; Havu-Nuutinen, 2005) consider that primary students' preexisting knowledge, prior to their introduction to formal primary school education, consists of strong visualizations of floating/sinking phenomena, which they explain using extensive quantities such as weight, length and volume.

The dominance of what Perkins and Grotzer (2005) describe as linear causal reasoning (attributing outcomes to a single property) over relational reasoning is a significant cognitive barrier. Relational reasoning requires comparing the densities of two substances and understanding the principle that an object will float if its density is less than that of the fluid and sink if it is greater. Without structured interventions, this transition from linear to relational reasoning is slow and incomplete during primary school years.

3.3. Vocabulary and Linguistic Ambiguities

Another factor complicating the teaching of density is language use. The scientific term "density" can be obscured by its everyday meanings, such as population density in geography or tree density in environmental studies (Xu & Clarke, 2012; Zongo *et al*., 2023). When students encounter "density" in multiple subject areas with different meanings, they may create fragmented mental models of the concept. For instance, a child might interpret density in science as "how much stuff is inside" without linking it to the precise mass/volume ratio definition.

Moreover, students frequently use "weight" and "mass" interchangeably, reflecting linguistic equivalence in everyday speech but causing semantic confusion in science. These linguistic challenges suggest that instruction should explicitly address terminology and its distinctions, reinforcing the unique definition of density in physical science contexts.

3.4. Influence of Scientific Language Across Subjects

The use of "density" in multiple disciplines (geography, environmental studies, and science) creates both opportunities and challenges for interdisciplinary learning (Seah *et al*., 2015). While cross-subject references can enrich understanding, they also risk reinforcing non-scientific definitions if teachers do not coordinate explanations. Some researchers (Xu & Clarke, 2012) argue for explicit discussion of these multiple meanings in science lessons, helping students differentiate and appropriately apply each definition.

For instance, population density is measured as the number of people per area, which is conceptually similar to mass per volume but differs in the "entities" and the scale of measurement. Drawing such parallels while highlighting differences can strengthen students' grasp of ratio- based reasoning across contexts.

3.5. Role of Measurement Skills in Understanding Density

The concept of density requires accurate measurement of both mass and volume. While most students can measure or estimate mass with relative ease, measuring volume (particularly of irregular objects) presents greater challenges (Smith *et al*., 1997). Even when students can calculate volume in mathematics class, they may fail to connect this abstract number to a physical property in science (Gaitanidi & Giannakoudakis, 2024).

Furthermore, volume is influenced by thermodynamic factors such as temperature and pressure, and in science education, units for liquids and solids (e.g., cm^3, mL) may be presented without explicit connections to the material measured. This can obscure the fact that density remains constant for a material under given conditions. Without a clear understanding of volume as distinct from mass, students struggle to comprehend density as a ratio.

3.6. Mathematical and Ratio Reasoning Challenges

Density is an example of an intensive quantity (a ratio of two variables that must be considered simultaneously) (Smith *et al*., 1997). Many students have difficulty with ratio reasoning, particularly when shifting from additive to multiplicative thinking (Ni & Zhou, 2005). They may assume that if mass increases, density must also increase, overlooking the counteracting effect of increased volume (Kloos, 2007). Similarly, a reduction in volume may be assumed to automatically reduce density, even if mass remains constant.

Even visual representations of ratios, such as "14 candies per bag," can be problematic for younger students (McMullen & Van Hoof, 2020). Translating this skill into the scientific concept of mass per unit volume requires an additional cognitive leap, one that not all students make by the end of primary school.

3.7. Ratio and Proportional Reasoning in Density Understanding

Several studies demonstrate the interplay between ratio reasoning and the mastery of density concepts. Density, as mass per unit volume, inherently requires proportional thinking, understanding how two variables change about each other. However, many primary school students approach these relationships additively rather than multiplicatively (Ni & Zhou, 2005; Vamvakousi & Vosniadou, 2010).

For instance, if both mass and volume increase, they may conclude density must also increase, ignoring the fact that proportional increases in both quantities can yield the same density. Research indicates that even when students are exposed to ratios in mathematics lessons, transfer to science contexts is not automatic (Gray *et al*., 2018; McMullen & Van Hoof, 2020).

The challenge lies in recognizing density as a constant ratio for a given material. Teachers who emphasize the multiplicative relationship and use visual aids, such as graphs plotting mass against volume, tend to foster better understanding. Such graphs can help students see that for a pure substance, the points lie on a straight line, with slope representing density (Smith *et al*., 1997).

3.8. Representational Levels of Scientific Understanding

A recurring theme in the literature is that students' understanding of density benefits from instruction that integrates all three representational levels: macroscopic, microscopic, and symbolic (Gabel, 1999; Hitt, 2005).

At the macroscopic level, students engage with tangible observations, such as comparing objects of different sizes and weights. At the microscopic level, they construct particle models to represent differences in material composition. At the symbolic level, they apply mathematical formulas, such as $\rho = m/V$.

However, Xu and Clarke (2012) found that many lessons address these levels separately rather than in an integrated fashion, limiting students' ability to connect their sensory experiences with particle models and symbolic reasoning. For example, a lesson on floating and sinking might be rich in hands-on observation but lack a follow-up particle-level explanation, leaving students with intuitive but incomplete mental models.

3.9. The Role of Particle Models in Conceptual Development

Microscopic representations, such as particle diagrams, are crucial for helping students understand why density remains constant for a given material under constant conditions. Visualizing density as the "crowdedness" of particles can make the abstract ratio concept more tangible (Smith, 1985). For example, two blocks of the same material but different sizes will have the same particle packing, reinforcing the idea that density is independent of size. Nevertheless, integrating particle-level reasoning with macroscopic observations remains challenging.

Students often fail to connect symbolic representations (formulas, graphs) with microscopic particle models, treating them as unrelated elements of the lesson (Xu & Clarke, 2012). Instruction that explicitly links these levels (e.g., by showing how measured mass and volume data align with particle diagrams) can bridge this gap.

3.10. The Role of Teacher Knowledge and Pedagogical Approaches

Teachers' content knowledge and pedagogical content knowledge (PCK) are crucial in shaping students' conceptual understanding of density. Studies have found that even preservice and in-service teachers may hold misconceptions similar to those of their students (Valanides, 2000; Dawkins *et al*., 2008; Hanuscin *et al*., 2018).

When teachers are uncertain about the particle theory of matter, the intensive nature of density, or the interpretation of floating/sinking phenomena, they are less able to anticipate and address student misconceptions effectively.

Moreover, curriculum constraints often force teachers to address density briefly, sometimes as an isolated topic, without sufficient time for conceptual reinforcement (Hashweh, 2015). In such cases, teaching may focus on procedural aspects (calculating density from mass and volume) rather than on developing deep conceptual understanding. Without returning to the concept in varied contexts over time, students are unlikely to retain a scientifically accurate understanding (Harrell & Subramaniam, 2014).

3.11. Classroom Interventions and Their Effectiveness

Several reviewed studies illustrate how targeted teaching interventions can help shift students' reasoning about density from intuitive to scientific.

These interventions often use guided inquiry, prediction-observation-explanation (POE) cycles, or structured problem- solving tasks. When students engage with phenomena that challenge their preconceptions (such as a small but dense metal object sinking faster than a large but less dense wooden object), they are more likely to question their initial reasoning and seek alternative explanations (Perkins & Grotzer, 2005). However, simply exposing students to counterexamples does not guarantee conceptual change. For deep learning to occur, students must have opportunities to reconcile new evidence with existing mental models (Kang *et al*., 2004).

This requires careful teacher facilitation, where probing questions encourage students to articulate their reasoning, identify inconsistencies, and construct more coherent explanations. Without this step, students may retain their original misconceptions even after observing contradictory evidence.

3.12. Impact of Teaching Learning Sequences (TLS)

Recent research in Greece and elsewhere has applied Teaching Learning Sequences (TLS) to the concept of density, combining hands-on experiments, modeling activities, and reflective discussions over multiple sessions (Gaitanidi, 2023; Gaitanidi & Giannakoudakis, 2024; Zoupidis *et al.,* 2016; Zoupidis *et al,* 2021).

TLS approaches provide sufficient time for students to revisit the concept in varied contexts, reinforcing both qualitative and quantitative aspects. For instance, students may begin by predicting outcomes of floating/sinking tasks, then measure mass and volume, calculate density, and finally model the particle arrangement for different materials.

Results from these TLS-based studies show improved differentiation between mass, volume, and density, as well as more consistent use of density as an explanatory variable in buoyancy phenomena. Because TLS spans several lessons, students have time to integrate new knowledge, which is essential for long-term retention (Harrell & Subramaniam, 2014).

3.13. Misconceptions Resistant to Change

Even with carefully designed instruction, some misconceptions persist. For example, the belief that “heavier objects sink” remains common when students encounter objects made from different materials but with similar sizes.

Similarly, confusion between mass and weight can resurface in new contexts, especially if students are exposed to inconsistent terminology in textbooks or across subjects. One explanation is that misconceptions are not merely factual errors but part of a coherent alternative framework students use to make sense of the physical world.

Dislodging such frameworks requires more than presenting correct information; it involves restructuring underlying conceptual relationships. In density instruction, this means continuously reinforcing that density is determined by both mass and volume together, and that changing one variable without the other has predictable effects.

3.14. Procedural vs. Conceptual Knowledge

Several studies distinguish between procedural knowledge (knowing how to calculate density) and conceptual knowledge (understanding what density represents and how it relates to other properties) (Heyworth, 1999; Dawkins et al., 2008).

Many students can perform the division m/V correctly, but cannot explain why two objects of different sizes but the same material have the same density. This disconnect suggests that procedural competence alone is insufficient for conceptual mastery.

Students who rely solely on memorized algorithms are more likely to misapply them in novel situations (Bar, 1987; Streefland, 1985). For example, when asked to compare densities of two liquids, they might choose the one with the greater mass as denser without measuring volume, reflecting incomplete integration of the ratio concept.

Students usually do not intuitively understand the aspect of analogy in these concepts (Kariotoglou & Psillos, 1993). Indeed, according to Kang *et al*. (2004), the reason why density is such a difficult concept is that it is a property of matter that cannot be directly perceived, but can only be understood through computation.

3.15. Analogical Reasoning and Its Limitations

Analogies (such as comparing density to “crowdedness” in a room) are often used to aid understanding. While they can be helpful in initial explanations, Analogies must be carefully scaffolded to avoid oversimplification (Lin *et al*., 1996). Students may take the analogy literally and make inappropriate inferences, such as thinking that density can be increased simply by “adding more particles” without considering the effects on volume.

Effective analogical reasoning in density instruction requires making explicit the similarities and differences between the analogy and the target concept. For example, a teacher might show that both crowded rooms and dense materials involve more entities per unit space, but unlike people in a room, particles in a solid cannot freely move to adjust the density under normal conditions.

3.16. Long-Term Retention and Revisiting the Concept

One consistent message in the literature is that density should not be treated as a one- time topic. Harrell and Subramaniam (2014), Gaitanidi and Giannakoudakis (2024), Zoupidis *et al*. (2016), Zoupidis *et al*. (2021) recommend revisiting the concept at multiple points in the curriculum, each time adding complexity and new contexts. For example, early lessons might focus on qualitative comparisons ("Which will float?"), middle grades might introduce measurement and calculation, and later lessons might connect density to particle theory, buoyancy, and material science applications.Such spiraling curricula align with cognitive development patterns, allowing students to refine their understanding as they acquire new mathematical and representational skills. Without this revisiting, misconceptions can resurface or remain hidden until more advanced topics reveal gaps in understanding.

3.17. Cross-Cultural and Cross-Curricular Perspectives

International studies reveal that misconceptions about density are not confined to a particular educational system. Some researchers (Zenger & Bitzenbauer, 2022) documented similar patterns among German secondary students, while other researchers (Xu & Clarke, 2012; Zoupidis *et al*., 2016) reported them for schools in Australia and Greece. This cross- cultural consistency suggests that the cognitive challenges are universal, rooted in the abstract nature of the concept and its reliance on ratio reasoning. However, curriculum design and teaching approaches vary, influencing the persistence and type of misconceptions. In systems where density is introduced early but revisited infrequently, students may retain procedural knowledge without deep conceptual understanding. Conversely, curricula that integrate density discussions into multiple topics (such as material properties, buoyancy, and states of matter) tend to produce more stable conceptual frameworks (Lederman & Lederman, 2015). Cross-curricular integration also has potential benefits. When density is linked to geography (population density) or environmental science (forest density), it can help reinforce the ratio concept, provided that teachers explicitly guide students in comparing and contrasting definitions across disciplines (Seah *et al*., 2015; Zongo *et al*., 2023).

3.18. Role of Formative and Diagnostic Assessment

Table 2 summarizes examples of diagnostic tools used to identify students' misconceptions about density. These tools range from multiple-choice concept inventories to open-ended problem-solving tasks and four-tier diagnostic tests (Kiray & Simsek, 2021). The literature shows that without such assessments, many misconceptions remain undetected until they hinder progress in more advanced science topics.

Table 2. Diagnostic tools for identifying density misconceptions in primary students.

Diagnostic Tool	Description
Multiple-choice concept inventories	Short tests containing common misconceptions as distractors to reveal students' conceptual frameworks about density.
Open-ended problem-solving tasks	Students explain reasoning in tasks involving mass, volume, and buoyancy to identify a misunderstanding of density as an extensive property.
Two-tier diagnostic tests	First tier asks for the correct answer, second tier probes reasoning; helps reveal underlying misconceptions.
Four-tier diagnostic tests	Extends two-tier with confidence rating for both answer and reasoning, enabling more precise identification of misconception strength.
Structured interviews	Semi-structured conversations allow deeper exploration of students' explanations and reasoning patterns.
Practical laboratory assessment	Hands-on tasks measuring mass and volume to observe procedural and conceptual difficulties in real time.

Formative assessment strategies, when embedded into instruction, can serve both as a diagnostic measure and as a learning opportunity. For example, teachers might present a floating/sinking prediction task mid-lesson, then prompt students to explain their reasoning. Comparing responses before and after targeted instruction can reveal shifts in understanding. However, many teachers select formative tasks based on convenience or familiarity rather than their diagnostic power. Effective diagnostic assessment must align with the specific conceptual hurdles identified in the literature. This includes distinguishing between mass and weight, recognizing density as an intensive property, and understanding the role of volume measurement. Misalignment between the assessment and the targeted misconception risks reinforcing, rather than correcting, misunderstandings.

3.19. Teacher Professional Development and Pedagogical Content Knowledge (PCK)

Several studies emphasize that improving student understanding of density requires strengthening teachers' PCK. Preservice teachers often held incomplete or incorrect conceptions of density themselves, affecting their instructional choices (Valanides, 2000). Teachers need both strong subject matter knowledge and familiarity with common student misconceptions to design effective learning sequences (Hanuscin *et al*., 2018). Professional development programs that focus on content-rich, inquiry-based strategies have shown promise. For example, training that models the integration of macroscopic, microscopic, and symbolic representations enables teachers to design lessons where students move fluidly between observing phenomena, building particle models, and applying formulas (Hitt, 2005; Johnson & Papageorgiou, 2009). However, systemic factors such as time constraints and rigid curricula can limit teachers' ability to implement these strategies. Without policy-level support, even well-trained teachers may default to procedural instruction under pressure to "cover" content quickly (Hashweh, 2015).

3.20. Interdisciplinary Opportunities and Cautions

Density's ratio structure makes it a candidate for interdisciplinary teaching that links science, mathematics, and other subjects. For example, in mathematics, proportional reasoning tasks can be framed with density contexts, while in technology or engineering lessons, material selection based on density can be explored. However, interdisciplinary work must guard against reinforcing superficial understandings. When "density" is used in different subjects without coordination, students may compartmentalize meanings. This is evident in cases where students correctly apply population density formulas in geography but fail to transfer the same ratio logic to material density in science (Xu & Clarke, 2012). Coordinated curriculum planning can help ensure that students see the underlying mathematical structure despite surface differences.

3.21. Importance of Revisiting and Reinforcing Concepts

A recurring recommendation is the spiraling approach, where density is reintroduced with increasing sophistication over multiple years. Early experiences may focus on qualitative sorting of materials by "heaviness for their size," later integrating measurements, and eventually linking to particle models and applications like buoyancy and material engineering. Such revisiting not only reinforces retention but also facilitates the gradual shift from linear to relational reasoning. It also allows students to integrate new mathematical skills (such as ratio and proportionality) into their science reasoning at the appropriate developmental stage (Gaitanidi & Giannakoudakis, 2024).

3.22. Implications for Science Education Policy

The persistence of density misconceptions suggests that curriculum frameworks should allocate more time and resources to this topic, viewing it as foundational for later topics in physics and chemistry. Teacher preparation programs must embed density instruction within broader discussions of intensive quantities, ratio reasoning, and scientific modeling. Additionally, assessment frameworks should incorporate diagnostic elements targeting density understanding, ensuring that misconceptions are addressed before they hinder further learning. Policies encouraging interdisciplinary collaboration can also enhance coherence in how ratio-based concepts are taught across subjects.

3.23. Long-Term Interventions and Sustained Conceptual Change

Interventions lasting several weeks or months, integrated into various science units, have shown greater success in achieving conceptual change compared to short, isolated lessons (Harrell & Subramaniam, 2014; Gaitanidi & Giannakoudakis, 2024). These long-term approaches provide opportunities to revisit misconceptions, present new contexts, and encourage connections between density and other scientific concepts such as pressure, buoyancy, and material classification. Sustained conceptual change also depends on embedding density in progressively complex tasks. For younger students, qualitative observations (such as comparing which objects sink or float) can be followed by guided measurement activities in later years. By upper primary, students can work with datasets, plotting mass and volume relationships, and interpreting slopes as density. In middle school, they can apply particle theory and connect density to industrial or environmental applications. This progressive approach aligns with Piagetian views on cognitive development, ensuring that conceptual demands match students' reasoning capabilities.

3.24. Comparative Effectiveness of Teaching Strategies

Table 3 synthesizes findings from comparative studies evaluating different teaching strategies for density. The most effective interventions combine hands-on experimentation, explicit conceptual discussion, and integration of macroscopic, microscopic, and symbolic representations (Smith *et al*., 1992; Johnson & Papageorgiou, 2009).

Table 3. Comparative effectiveness of teaching strategies in density instruction.

Teaching Strategy	Key Features	Observed Effectiveness
Lecture-based instruction	The teacher explains the definition and formula, followed by worked examples.	Improves procedural skills but often leaves misconceptions intact; limited conceptual change.
Algorithmic calculation drills	Focus on repeated m/V calculations without conceptual discussion.	Students master formula use but fail to transfer knowledge to novel contexts.
Prediction-Observation-Explanation (POE)	Students predict outcomes, observe results, and reconcile differences with scientific explanations.	Highly effective in confronting misconceptions and promoting conceptual reasoning.
Inquiry-based learning	Students' investigation Density phenomena through guided experiments and reflection.	Supports deeper understanding and integration of representations; requires more time and teacher facilitation.

Table 3 (Continue). Comparative effectiveness of teaching strategies in density instruction.

Teaching Strategy	Key Features	Observed Effectiveness
Visual-particle modeling	Uses diagrams to show particle arrangement for different materials.	Helps link microscopic and macroscopic perspectives, especially for the intensive property concept.

Approaches relying solely on lecture or algorithmic calculation tend to improve procedural skills but leave misconceptions untouched (Heyworth, 1999). In contrast, inquiry-based methods that require prediction, experimentation, and explanation foster deeper understanding. The Prediction-Observation-Explanation (POE) model is particularly effective, as it confronts misconceptions directly by prompting students to articulate their expectations, observe outcomes, and reconcile differences. TLS-based instruction (Gaitanidi, 2023) ranks highly in effectiveness because it combines multiple strategies over an extended time frame. It supports gradual conceptual refinement and promotes retention, making it a strong candidate for integration into primary science curricula.

3.25. Challenges in Implementation

Despite the evidence supporting multifaceted, long-term approaches, practical barriers remain. Time constraints, crowded curricula, and assessment systems focused on short-term performance discourage teachers from investing in extended conceptual development. Additionally, limited access to laboratory equipment in some schools constrains opportunities for hands-on work, leading to reliance on demonstrations rather than student-led experiments (Dawkins *et al*., 2008). Professional development can help teachers adapt by using low-cost, everyday materials to model density phenomena. For example, using kitchen scales, measuring cups, and household objects can make density investigations accessible without specialized laboratory tools. However, this requires teacher creativity and confidence in managing open-ended investigations.

3.26. Integrated Model, Future Research, and Policy Directions for Density Education

Drawing on the literature, an integrated conceptual model for density instruction should include:

(i) Early introduction through sensory-rich experiences: using floating and sinking, comparing “heaviness for size,” and sorting materials.
(ii) Explicit differentiation of mass, weight, and volume: emphasizing correct scientific vocabulary and measurement techniques.
(iii) Progressive integration of ratio reasoning: linking density to proportionality in mathematics.
(iv) Representation at all three levels: macroscopic (observations), microscopic (particle models), and symbolic (formulas and graphs) presented in connected ways.
(v) Ongoing diagnostic assessment: identifying and addressing misconceptions continuously.
(vi) Reinforcement across contexts: revisiting density concerning buoyancy, material science, and other topics to strengthen conceptual stability.

By embedding these elements within a spiraling curriculum, density can be developed as a stable and transferable scientific concept rather than a fragmented procedural skill. The review reveals significant gaps in classroom-based intervention studies, especially in early primary grades.

Future research should focus on:

(i) Design-based research to iteratively refine teaching sequences in authentic classroom environments (Zoupidis *et al*., 2016; Gaitanidi & Giannakoudakis,2024).
(ii) Longitudinal tracking of students' density understanding over multiple years to determine retention and transfer effects.
(iii) Cross-cultural comparisons to explore how curricular structures and cultural contexts influence misconception persistence.
(iv) Assessment tool development to detect subtle conceptual differences, particularly between mass-weight and weight-density confusions.
(v) Teacher-focused interventions evaluating how PCK growth translates into improved student outcomes.

Additionally, research could explore the role of digital simulations in supporting microscopic and symbolic representations, especially where physical experimentation is constrained. Simulations can make particle-level reasoning more accessible and allow manipulation of variables that are difficult to change in real-life settings. The findings have implications not only for classroom practice but also for policy.

Education authorities should:
(i) Allocate sufficient curriculum time for density instruction across multiple grade levels.
(ii) Support interdisciplinary curriculum planning so that ratio reasoning is reinforced consistently in mathematics, science, and other subjects.
(iii) Provide teacher training focused on conceptual change strategies, representation integration, and diagnostic assessment.
(iv) Encourage resource-sharing networks for low-cost density investigations, particularly in resource-limited schools.

Such systemic changes would create conditions for sustained improvement in density understanding, reducing the prevalence of misconceptions documented over the past five decades. From the synthesis of fifty years of research, several conclusions emerge:
(i) Misconceptions about density are persistent, universal, and multifaceted. They stem from linguistic confusion, ratio reasoning challenges, measurement difficulties, and reliance on sensory-based intuition.
(ii) Effective teaching requires integration of multiple strategies—hands-on work, explicit conceptual discussion, multi-level representations, and continuous assessment.
(iii) Long-term, spiraling instruction is essential for stable conceptual development. Short, isolated lessons rarely produce lasting change.
(iv) Teacher knowledge is a critical factor, both in anticipating misconceptions and in designing lessons that connect macroscopic, microscopic, and symbolic understandings.
(v) Policy support is needed to create the time, training, and resources necessary for effective implementation.

By adopting an integrated approach informed by these insights, educators can more effectively guide students toward a scientifically accurate and durable understanding of density, laying a foundation for more advanced scientific learning in later education.

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6. CONCLUSION

This review demonstrates that density remains a challenging concept for elementary students due to misconceptions, ratio reasoning difficulties, and measurement challenges. Addressing these requires integrated teaching that connects macroscopic, microscopic, and symbolic representations while clarifying linguistic and conceptual distinctions. Long-term, inquiry-based approaches supported by diagnostic assessments are essential for lasting conceptual change. Teacher professional development and curriculum planning should prioritize strategies that confront misconceptions directly and revisit density over time. Such measures can strengthen students' scientific literacy, enabling them to apply the concept of density accurately in diverse scientific and real-world contexts.

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