

# Students' Misconceptions and Mental Models about Floating, Suspension, and Sinking: A Systematic Literature Review

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**Abstract:** This systematic literature review examined research on students' misconceptions and mental models related to floating, suspending, and sinking (FSS) concepts published between 1990 and 2026. The review aims to map research themes, major forms of misconceptions, classifications of mental models, and instructional interventions used to support scientific understanding. The review implemented the PRISMA framework to identify, screen, and ensure the eligibility of the articles. A total of 215 articles met the inclusion criteria. Findings show that misconceptions remain the most investigated aspect, particularly those involving confusion among density, mass, volume, and buoyant force. Research on mental models is still limited, revealing that many learners rely on initial or synthetic, context-dependent representations rather than scientific models. Instructional interventions are the most extensively and widely investigated, including hands-on activities, conceptual change strategies, simulations, and structured learning models, each contributing differently to addressing misconceptions and promoting scientific mental models about FSS phenomena. Overall, the review highlights persistent conceptual difficulties, insufficient assessment tools, and a need for more integrative research that connects misconceptions, mental models, reasoning, and diagnostic measurement. Strengthening appropriate interventions will support deeper insights into learners' scientific understanding and mental models of FSS concepts.

**Keywords:** Floating; Mental model; Misconception; Sinking; Suspending

## Introduction

Constructivist perspectives assert that learners enter the classroom with pre-existing ideas about science, shaped by their prior experiences, textbooks, teachers' explanations, and everyday language. According to this view, learners frequently construct their own knowledge and formulate personal theories about how the natural world operates. Consequently, the knowledge structures or conceptions they generate may at times conflict with theories accepted by scientists. For instance, children often exhibit misconceptions

when explaining why some objects float when submerged in water while others sink.

Beyond classical constructivist perspectives, contemporary research in science education increasingly emphasizes the roles of knowledge-in-pieces, resource theory, and conceptual ecology in explaining why misconceptions in physics tend to be persistent and context dependent. From this perspective, students' understanding of floating, suspending, and sinking (FSS) phenomena is not constructed as a single coherent conceptual framework, but rather as a collection of fragmented cognitive resources that are activated

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situationally (diSessa, 1993; Hammer, 2000). Consequently, learners may demonstrate scientifically acceptable reasoning in one context, while reverting to intuitive explanations in another context that is physically equivalent.

Cross-cultural and instructional studies further indicate that misconceptions related to FSS are shaped not only by everyday experiences, but also by instructional language, textbook metaphors, and visual representations employed by teachers (Lemke, 1990; Treagust & Duit, 2008). Terms such as light, heavy, and pushed upward are frequently used in non-technical ways, reinforcing non-scientific interpretations of buoyant force and density. In this sense, misconceptions should not be viewed solely as individual cognitive errors, but rather as outcomes of complex interactions among linguistic, pedagogical, and cultural factors within the learning environment.

The topic of floating and sinking has been widely examined, ranging from preschool children with no formal educational background to university students. Research has revealed multiple dimensions of learners' conceptions related to this phenomenon. Wongsuwan et al. (2019) investigated misconceptions held by high school learners, which they characterized as alternative conceptions concerning foundational ideas related to buoyant force, including mass, volume, depth, pressure, and density. Mansyur et al. (2022) focused specifically on the notion of a suspending object and explored patterns of external representations associated with density concepts. Chirayangyuenyong et al. (2023) examined learners' understanding of buoyant force and its relation to differences in fluid pressure. These studies collectively indicate the presence of mental models—internal representations categorized as initial and synthetic models, that do not align with established physical laws that are categorized as scientific models (Vosniadou & Brewer, 1992). Thus, it is essential to systematically review studies that investigate the forms of misconceptions, approaches for addressing them, and ways to support the development of scientific mental models in the context of floating, suspending, and sinking (FSS) phenomena.

In many instructional contexts, floating and sinking concepts are taught procedurally, with emphasis placed on observable outcomes—whether an object floats or sinks—rather than on the causal mechanisms underlying these phenomena (McDermott & Redish, 1999; Hestenes, 2010). Such instructional practices may encourage outcome-based reasoning, in which students memorize patterns without developing an integrated understanding of the relationships among object density, fluid density, and displaced fluid volume. As a result, learning experiences often fail to promote the

restructuring of students' mental models toward stable scientific models.

Several researchers, such as Yin et al. (2008), Chien et al. (2009), and Teo et al. (2017), have examined learners' conceptions of the properties and states of objects in liquid media. Other studies have proposed instructional design innovations (Minogue et al., 2015; Castillo et al., 2017; Gette et al., 2018) and contributed to the development of assessment instruments (Viyanti et al., 2017; Kafiyani et al., 2019) focusing on these topics. Kaharu et al. (2021) developed a test to explore a broader conceptual domain by incorporating the idea of neutral buoyancy. Dorji (2021) studied learners' conceptions of how weight and volume influence the floating–sinking behaviour of objects. Similarly, Leuchter et al. (2014) documented persistent misconceptions among elementary school learners, which were reduced only following structured instructional interventions. Kim et al. (2021) further investigated first-year university students majoring in physics and chemistry, revealing that their understanding of buoyant force was attributed to material-related properties rather than to the volume of displaced fluid.

Within the category of systematic literature review (SLR), a number of studies have examined the concepts of floating, sinking, and suspended states (FSS). Castillo-Hernández et al. (2025) applied SLR procedures to analyze publications in science education related to floating and sinking phenomena over the past five decades. Schwichow et al. (2024) reviewed various forms of instructional approaches used to teach FSS concepts. However, no SLR studies have specifically integrated and examined misconceptions and mental models associated with their assessment and interventions in the concepts encompassed within static fluids.

From a cognitive perspective, mental models play a central role in mediating between external representations—such as diagrams, graphs, and experiments—and learners' internal reasoning processes (Johnson-Laird, 1983; Gilbert & Boulter, 2000; Greca & Moreira, 2000). Without systematic attention to learners' mental models, research on misconceptions risks remaining descriptive, focusing on what students misunderstand without adequately explaining how and why conceptual change occurs. For this reason, several scholars have argued for stronger integration between research on misconceptions, mental models, and instructional interventions in science education (Duit & Treagust, 2003; Chi & Roscoe, 2002).

Therefore, a focused and integrative literature review is needed to bridge the fragmented findings of existing studies on floating, suspending, and sinking (FSS), explicitly linking misconceptions, mental models, and the underlying cognitive processes. Without such

integration, prior studies tend to remain descriptive and fragmented, thereby limiting their capacity to contribute to theory-informed instructional design and the development of robust diagnostic assessments. This study addresses this gap by synthesizing findings across conceptual and pedagogical dimensions to strengthen the scientific foundation of research on FSS phenomena.

Although numerous studies have examined students' misconceptions, instructional strategies, and learning outcomes related to floating and sinking, research that explicitly integrates misconceptions and mental models within a unified analytical framework remains limited. Existing systematic reviews tend to focus either on instructional approaches or on conceptual difficulties in isolation, leaving the cognitive mechanisms underlying learners' reasoning underexplored. This condition highlights the need for an integrative systematic literature review that synthesizes misconceptions, mental models, assessment approaches, and instructional interventions related to floating, suspending, and sinking phenomena.

Within this SLR framework, the present study synthesizes and integrates findings from dispersed research in order to develop a comprehensive understanding of how FSS concepts have been investigated over time. These concepts are not only fundamental to fluid physics but also underpin learners' understanding of Archimedes' principle, density, buoyant force, and the equilibrium of objects in fluids. Through an SLR approach, researchers can trace the forms of misconceptions that emerge, the ways these concepts are taught, and how learners' mental models form and evolve during the learning process.

To establish a strong foundation for advancing FSS instruction, a systematic mapping of prior research is required. This SLR aims to provide a comprehensive overview of: (a) the dominant themes of FSS-related research between 1990 and 2026; (b) the forms of misconceptions consistently reported during this period; (c) the categories and types of mental models explored; and (d) the forms of instructional interventions used to address misconceptions and foster the development of scientific mental models regarding FSS.

This study is expected to contribute to the development of conceptually grounded physics instruction, particularly by helping teachers and researchers better understand how learners' reason about everyday phenomena related to FSS. Furthermore, the results of this SLR may serve as a foundation for designing more accurate diagnostic instruments and pedagogical approaches grounded in the reconstruction of learners' mental models.

Fundamental considerations underscore the need for a systematic review of misconceptions and mental

models related to FSS concepts. First, there has been a noticeable increase in publications on this topic in recent years across primary, secondary, and higher education contexts. However, much of this research remains fragmented, with studies on misconceptions and those on mental models often conducted separately, despite the fact that both represent interrelated dimensions of conceptual thinking. Second, there is still a limited number of literature reviews that specifically examine how misconceptions and mental models in FSS develop, as well as how instructional intervention strategies can influence conceptual change and the restructuring of learners' mental models.

By conducting a systematic analysis of literature published between 2000 and 2025, this study aims to update the contemporary research landscape concerning misconceptions and mental models in FSS; while considering the paradigm shifts in science education that increasingly emphasize constructivist and learning approaches. This analysis is also expected to identify research gaps that may serve as a foundation for future investigations in this area.

## Method

This study traced and analysed scientific publications related to misconceptions and mental models on FSS concepts across various educational levels. The primary purpose of this SLR is to map research aspects, methodological approaches, and major findings concerning learners' misconceptions and mental models, as well as instructional strategies employed to address misconceptions and foster the development of scientific mental models in the context of FSS. Consistent with other systematic reviews in education, this SLR follows established scientific procedures (Mengist et al., 2020), including: (1) formulating the conceptual framework and research questions; (2) designing a data search strategy; (3) determining selection criteria; and (4) conducting data analysis and synthesis.

### *Search Strategy*

To conduct this SLR, we adopted the PRISMA framework (Page et al., 2021) and used Publish or Perish software version 8 for the literature search, as illustrated in Figure 1. The literature search was conducted using the Scopus database which provides broad coverage of publications in physics and science education. The search was limited to articles published between 1990 and 2026 to ensure the relevance of findings. Keywords used in the search included floating, suspending, sinking static fluid, buoyancy, buoyant force, Archimedes' principle, and Archimedes' law, and each combined with the term education, misconception,

mental model, assessment, teaching, learning, or instructional.

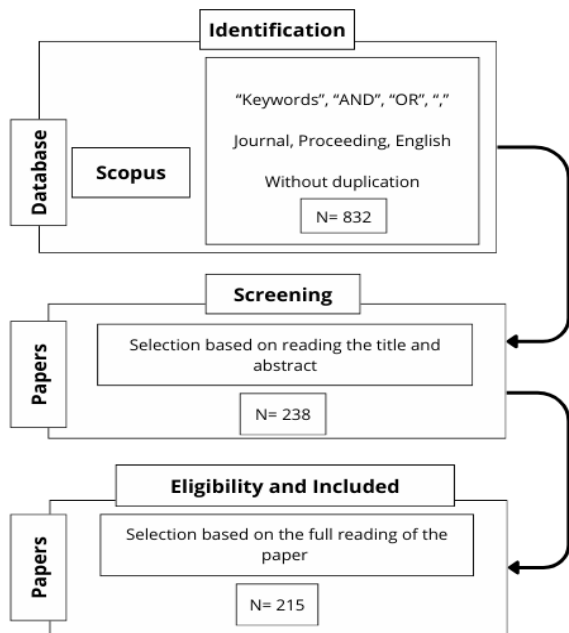


Figure 1. The application of the PRISMA framework in the search and selection of articles

Because different sequences of AND and OR combinations yield different results, both AND-OR and OR-AND combinations were employed. This search strategy produced 60 keyword combinations applied in the application, resulting in 403 unique articles after removing duplicates.

In addition to using Boolean AND and OR operators, the same keywords were also combined using only a comma (,). The characteristics of the Publish or Perish application allow the use of this pattern and, in fact, generate more search results than Boolean operators.

Keyword combinations using commas were applied to retrieve articles containing the specified keywords and to identify article titles that matched them. This process continued until a saturation point was reached, where no new articles were identified. Using this approach, 35 keyword combinations yielded 583 unique articles. Overall, the combined use of AND-OR, OR-AND, and comma-based keyword patterns resulted in a total of 832 unique articles with no duplication. These keywords and their combinations were used to identify relevant studies, which were subsequently screened based on topical relevance and publication quality. Following article collection, screening was performed by examining the titles, abstracts, and full texts of each study, with particular attention to the keyword’s misconception, mental model, perception, understanding, reasoning, critical thinking, creative thinking, assessment, teaching,

learning, and instructional for categorization. The search was restricted to Scopus-indexed journals and proceedings articles published in English to ensure readability and academic validity.

Selection Criteria

To ensure alignment with the study’s objectives, inclusion criteria were applied as follows: articles published between 1990 and 2026 included in the Scopus database; addressing FSS concepts; written in English; studies conducted within the context of science and physics education at all educational levels. The exclusion criteria were theses or non-journal/proceeding reports; articles discussing fluid topics unrelated to FSS concepts; articles focused on fluid engineering or applied mechanics without an educational context. The exclusion process based on these criteria reduced the initial set of 832 articles to 238. A total of 594 excluded articles belonged to the domain of fluid engineering or other unrelated fields. Examples of articles in this category include “Floating under a levitating liquid,” “Fouling of floating plastic debris under Biscayne Bay exposure conditions,” and “Floating fishes: an activity investigating overfishing, buoyancy, and gas compressibility,” among others. Although these articles contained keywords such as floating, fluid, and buoyancy, they were not relevant to the focus of this study. Following a content-based screening, 215 articles remained and were deemed suitable for further analysis.

Result and Discussion

Research Aspects Related to FSS

Content analysis revealed that, of the 215 articles reviewed, seven major thematic aspects were most frequently examined, as illustrated in Figure 2.

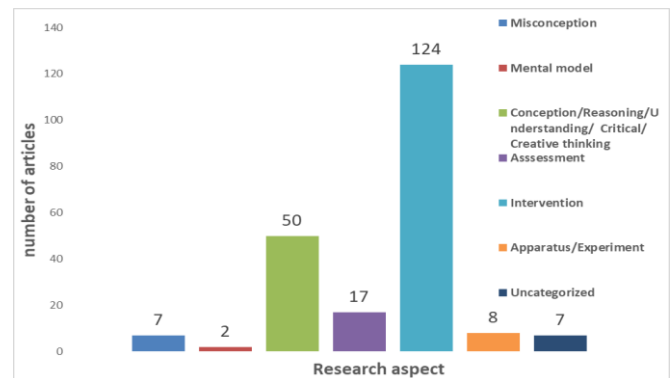


Figure 2. Diagram of number of articles based on research aspects

Figure 2 shows that there are seven studies (included in Scopus-indexed journals) that explicitly used keywords and explored misconceptions about floating, suspending, and sinking, and concepts related

to static fluid. The central issue in learning about floating, suspending, and sinking has remained tied to students' misconceptions regarding density, volume, buoyant force, and the interrelationships among these concepts. The misconception-related studies reflect the fact that these concepts are inherently challenging, abstract, and frequently misunderstood, particularly by elementary, secondary, and university students. Most studies appear to emerge from the urgent need to map existing misconceptions before appropriate instructional solutions can be designed.

If the term misconception is understood as being closely related to alternative conception, naïve conception, and misunderstanding, it can be stated that research on misconceptions (published in Scopus-indexed journals) is not limited to only seven studies. There is an overlap between a group of 50 articles. Likewise, this number would differ if misconceptions were categorized as initial models or synthetic models within the framework of non-scientific mental models. This implies that all studies on misconceptions can be grouped under mental model research, specifically within the category or level of non-scientific models.

Figure 2 also shows that interventions (teaching or instructional methods, approaches, strategies) constitute the most dominant research focus, with a total of 124 studies. The interventions were addressed to misconceptions and critical thinking, understanding, and other aspects of teaching and learning purposes.

The second predominant aspect of research is grouped into one category (50 articles), i.e. conception, perception, critical thinking, creative thinking, understanding, and reasoning.

There are 17 articles as test development to explore misconceptions, mental models, and other aspects of teaching and learning about sinking, suspending, and sinking concepts. In this context, we differentiate between misconception studies and test development studies.

Of the 17 articles related to assessment development, one article was explicitly aimed at probing misconceptions; however, the concepts examined were not limited to floating and sinking but also included mechanics and static fluid concepts more broadly, such as hydrostatics. In addition, among these 17 articles, two focused on the development of assessments to elicit mental models. One article specifically investigated mental models in basic static fluid concepts, within which floating and sinking were included, while the other addressed mental models of static fluid concepts more generally, such as Archimedes' principle, Pascal's law, surface tension, and capillarity.

Studies that explicitly examined and used the keyword mental model in relation to floating, suspending, and sinking include the work of Mansyur et

al. (2022). Other studies, such as Taher et al. (2017), investigated mental models related to Archimedes' principle. Both studies categorized mental models into initial, synthetic, and scientific models.

This SLR cannot assert that only two studies published in Scopus-indexed journals have examined mental models of floating, suspending, and sinking and related static fluid phenomena. Concepts such as misconception, alternative conception, pre-conceptions, naïve conception, understanding, reasoning, cognitive structure, and related aspects may also be associated with mental models. However, this SLR can only state that, implicitly, there is a substantial body of research that addresses mental models related to these phenomena. The aspects of mental models explicitly appear in only two studies.

There are implicit overlaps between studies on mental models and other aspects such as misconceptions, reasoning, and understanding. Referring to the framework of Vosniadou et al. (1992), which classifies mental models into three levels, i.e., initial, synthetic, and scientific models, where misconceptions can be grouped within initial or synthetic models as non-scientific mental models. Based on this framework, the number of studies that investigate mental models amounts to seven articles, consisting of two studies that explicitly address mental models and five studies that implicitly examine them as part of mental model research.

Understanding mental models is crucial for explaining why misconceptions form and persist, while studies on reasoning are essential for examining how learners apply causal logic when explaining physical phenomena. This imbalance implies that research in this field remains largely superficial, aspect-focused on descriptive accounts of misconceptions rather than exploration of the underlying cognitive processes.

There are 17 studies that developed assessment-related aspects of misconception, understanding, mental model, reasoning, and critical thinking. Of the 17 articles, some focused on developing tests to probe misconceptions, while fewer studies were explicitly related to mental models. This suggests that the development of instruments for measuring students' understanding of FSS phenomena is still highly limited. In fact, valid and reliable assessment tools are critical for diagnosing misconceptions and evaluating the effectiveness of instructional interventions. The low attention given to this aspect indicates a strategic research gap that could be addressed in future studies, such as through the development of two-tier diagnostic tests.

Instructional interventions constitute the largest research focus, with 124 studies. This reflects a growing interest in designing strategies to address

misconceptions, such as inquiry-based experiments, PhET simulations, multi-representational approaches, and cognitive-conflict-based instructional models. Although fewer in number than misconception studies, these findings indicate a transformative shift from merely identifying problems to seeking pedagogical solutions that are applicable and contextually relevant in the classroom.

Overall, research conducted between 1990 and 2026 reveals an imbalance across the thematic aspects examined. The emphasis on interventions needs to be complemented by more robust research on misconceptions, mental models, reasoning, and assessment to support the development of a more comprehensive understanding of FSS learning.

In addition to the dominance of misconception and intervention-oriented studies, several scholars have emphasized that research trends in FSS learning also reflect broader paradigmatic shifts in science education. Persistent conceptual difficulties in buoyancy-related topics have motivated the growth of intervention-based research while simultaneously revealing the limitations of traditional content-transmission models. Indonesian research on static fluid concepts consistently reveals a strong focus on identifying and addressing student misconceptions across educational levels. The evidence is robust, with multiple studies documenting widespread conceptual misunderstandings. For instance, Atmaja et al. (2024) found 88.5% of students had misconceptions in hydrostatic pressure, Pascal's law, and Archimedes' law. Busyairi et al. (2024) further confirmed that students often misinterpret concepts through inaccurate everyday intuitions. Kamilah et al. (2025) systematically reviewed 61 articles, highlighting static fluids as the most frequently studied misconception topic. The research suggests a clear pedagogical trajectory: using diagnostic tools like four-tier tests and interventions such as computer simulations to scaffold students from intuitive reasoning toward more sophisticated, density-based conceptual understanding. Moving forward, research should increasingly integrate these aspects, so that scholars not only identify what students' misconceptions are but also explain how their cognitive structures develop and determine how these can be measured accurately to support more effective and sustainable instructional interventions.

#### *Prominent Forms of Misconceptions*

Based on the data presented in Figure 2 regarding research aspects related to FSS, particularly those concerning misconceptions, this section outlines some forms of misconceptions identified by researchers. Mellu et al. (2022) found 36% of learners experienced misconceptions. They cannot analyze the relationship

between density, object weight, and buoyant force in the context of floating and sinking phenomena. In the study by Bessas et al. (2024), 44.70% of learners demonstrated misconceptions related to mass and volume as the primary determinants of buoyant force, without considering density as a critical factor. These findings are consistent with earlier studies (Yin et al., 2008; Zoupidis et al., 2021), which similarly identified difficulties in distinguishing among density, mass, and volume.

Comparable misconceptions were also reported by Unal (2008), where 39% of learners believed that volume determines whether an object sinks or floats; 68% assumed that weight is the determining factor. A substantial percentage of learners (64%) considered the volume of liquid in the container as the factor influencing whether an object sinks or floats. This indicates that learners often focus on superficial aspects or observable features, rather than the substantive properties of floating and sinking as inherent attributes of the object. FSS is not merely about the position of an object in a liquid but reflects the object's inherent identity when placed in a fluid. Learners assumed that larger objects sink while smaller one's float. Kiray et al. (2015) found 74 types of misconceptions about sinking-floating related to shape, the existence of holes or hollowness, hardness or softness, and some other aspects of an object. Regarding the presence of hollowness in objects, Bessas et al. (2024) found 63.29% of learners showed misconceptions about the floating behavior of hollow versus solid bodies.

Bozkurt et al. (2022) found that pre-service teachers hold misconceptions regarding the motion of an object that initially floats after it is pushed into a fluid and then released, which contrasts with previous research. Mamontsuo et al. (2024) found preschool teachers possess only partial understanding of floating and sinking concepts. While they can describe basic principles, their explanations for why an object floats or sinks remain limited. Many teachers stated that objects float because they are light. Comparisons between the weight of the object and the weight of water were among the explanations teachers used. Object shape and material were also perceived as determinants of whether an object would float or sink.

Unal (2008) also identified misconceptions such as: objects with holes will eventually sink as liquid enters the holes (64%); when a floating object is cut in half, the smaller piece will sink to a lesser extent (50%); when a floating object is cut in half, the larger piece will sink or its submerged volume will increase (54%). Similarly, Bessas et al. (2024) reported that 31.9% of learners believed that surface area determines whether an object floats or sinks. Furthermore, for cases where only part of the object is submerged, 73.4% of learners were unable

to determine correctly whether the object was floating or sinking. Similar observations were also reported by Minogue et al. (2015) and Minogue et al. (2016), and can be categorized as intuitive models, alternative conceptions, or misconceptions (Yin et al., 2008).

These findings are consistent with previous studies highlighting similar challenges. From a theoretical standpoint, the persistence of misconceptions in floating, suspending, and sinking phenomena can be explained through the lens of phenomenological primitives, in which learners activate intuitive knowledge elements that are productive in everyday contexts but fail in formal physics explanations (diSessa, 1993). Phenomenological primitives explain the persistence of floating and sinking misconceptions by revealing how learners apply intuitive but scientifically incorrect knowledge across different contexts. Studies demonstrate that students systematically misunderstand buoyancy by incorrectly associating floating behavior with object mass or volume rather than density relationships (Hammer, 1996; Dorji, 2021). Empirical research in multiple educational settings, including Indonesian classrooms, consistently shows students treat buoyant force as a material property of objects instead of an interactive fluid displacement process (Sukariasih et al. (2024). These misconceptions are robust because they emerge from everyday intuitive thinking patterns that students apply indiscriminately, making them resistant to traditional instructional interventions. Students frequently misunderstand buoyancy as an inherent material property rather than an interactive fluid displacement process, leading to persistent conceptual errors. The research reveals that students often incorrectly categorize buoyancy as a static characteristic of objects instead of a dynamic interaction between objects and fluids. This ontological miscategorization explains why students can correctly predict floating behavior in one scenario but fail in physically equivalent situations. Wicaksono et al. (2019) supports this finding, noting that students experience significant difficulties understanding buoyancy, particularly in situations involving suspended objects. Sholahuddin et al. (2019) further confirm that 38.71% of misconceptions relate to the relationship between immersed volume and buoyant force. This fundamental misunderstanding contributes to the resilience of misconceptions, making simple formula exposure ineffective in creating lasting conceptual change.

#### *Categories and Types of Mental Models*

The findings of mental model studies identified through this SLR are presented below, with the discussion limited to articles that explicitly examine mental models related to these phenomena.

Mansyur et al. (2022) found that across educational levels, learners' mental models tend to shift from the initial category to synthetic, from synthetic to scientific, and/or directly from initial to scientific. The proportions reported were as follows: for elementary students, 64% were categorized as initial; for junior high school students, 44%; for senior high school students, 34%; and for university students, 26%. The decrease in the proportion of initial models was accompanied by an increase in the proportion of scientific models—10%, 26%, 24%, and 39% respectively, while transitional (synthetic) models accounted for 26%, 30%, 42%, and 35%.

Mansyur et al. (2022) also explored the types of mental models by labelling or naming them according to their characteristics. Several initial or synthetic mental models identified included the water as a sinker model, the air as a floater model, the leaked boat model, and others. The findings indicate that the mental models adopted by learners depend strongly on the context of the presented phenomena. Although the scientific model category was dominant when learners evaluated factors causing objects to float, suspend, or sink, the density-based model (DbM) was applied inconsistently across different contexts. Even when learners referred to density as the key concept, their reasoning was still influenced by shape, surface area, the presence of holes, hollowness, trapped air, and changes in water height.

Mansyur et al. (2022) further showed that many participants believed air to be a factor that could change an object from sinking to suspending or floating, from suspending to floating, or from floating to "more floating." A substantial proportion of participants (more than 50%) held a model in which air-filled cavities push objects upward. Some participants referred to density but compared the density of air with the density of water, stating that filling a cavity with air causes the object to change its state in water because air has a lower density than water. This reasoning suggests a mental model like the idea of air as an active force lifting the object upward, perhaps influenced by analogies with air-filled balloons.

The categorization of mental models into initial, synthetic, and scientific levels aligns with broader findings in conceptual change research. Vosniadou & Brewer (1992) emphasizes that synthetic models are not merely transitional errors but represent coherent explanatory systems that integrate everyday experience with fragments of scientific information. In FSS contexts, such synthetic models often incorporate density terminology while still relying on intuitive notions such as air pushing objects upward or water exerting a direct lifting force.

Johnson-Laird (1983) further notes that mental models are dynamic and task-dependent, meaning that

the same learner may activate different models depending on representational format or contextual cues. This perspective helps explain why students who demonstrate scientific reasoning in numerical density problems may revert to intuitive explanations when confronted with pictorial or real-world scenarios. Consequently, mental model research provides critical insight into the instability of learners' understanding and underscores the need for instruction that promotes model coordination rather than mere model replacement.

Based on the analysis by Mansyur et al. (2022), it can be concluded that students' mental models generally remain within the initial and synthetic levels and are highly context dependent. Some students exhibited scientific models for certain suspending-related phenomena while retaining initial or synthetic models for others. Mental model levels also tend to correlate with grade level, reflecting the influence of curriculum and learning environment. The synthetic level serves as a transitional stage between initial and scientific models, with the highest proportion found among senior high school students. There is also a tendency for students' mental models in floating and sinking contexts to influence their assumptions about suspended-state phenomena. Moreover, shortcut patterns and oversimplifications occur when representing suspended objects—students frequently choose intermediate positions between floating and sinking without considering the density-based reasoning underlying suspension. These tendencies suggest that teaching floating and sinking concepts without adequate emphasis on suspended states is insufficient. The assumption that addressing floating and sinking automatically addresses suspension is not supported by these findings. Instructional materials should therefore present suspended objects at varied positions between the surface line and the container bottom. Furthermore, cases where suspended objects rest at the bottom should be supplemented with explicit explanations that “a suspended object may remain at the bottom.” Substantive aspects of density must be emphasized to reduce initial or synthetic models. Future studies may recruit participants proportionally across grade levels to more precisely observe transitions between mental model stages.

Research related to mental models in FSS has also been conducted by Gustina et al. (2024), although their study focused on mapping mental models based on thinking styles. The characteristics of the mental models themselves were not identified in that study.

*Forms of Instructional Interventions*

Based on the categorization results, several dominant forms of instructional interventions were

identified in FSS learning, implemented either directly to address specific misconceptions related to FSS concepts or applied as general instruction without explicitly targeting misconception reduction. The frequencies of the intervention groups (models, methods, approaches, and media) are presented in Figure 3.

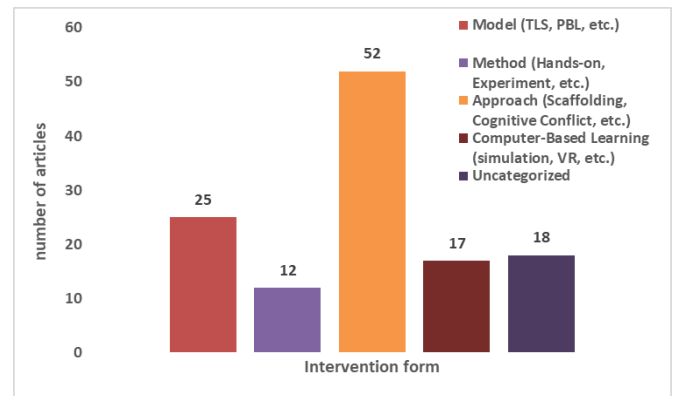


Figure 3. Diagram of instructional interventions form for FSS concepts

Figure 3 shows that there are 25 studies concerned with interventions based on structured instructional models such as the TLS density-based model and POE (Zoupidis et al., 2021), the 5E Learning Cycle (Harrell et al., 2022), the 5E model integrated with a conceptual-change framework Çepni, et al. (2010), application of scaffolding structures in learning, and active learning through structured interactive approaches (Radovanović & Sliško., 2013), which also follow POE/5E patterns emphasizing exploration and reflection. The 5E Learning Cycle emphasizes investigation, discussion, and conceptual reflection.

Figure 3 shows 12 studies categorized as hands-on interventions. These interventions emphasize direct experimentation, manipulation of physical objects, and experiential activities. Studies within this category include hands-on activities designed to modify floating-sinking misconceptions (Unal, 2008); direct experimentation to explore alternative conceptions and activity and question-based lesson plans (Dorji, 2021), and direct observation using everyday materials (Pratamawati, 2024). Such interventions provide concrete experiences that reinforce the understanding of density, buoyant force, and fluid properties through direct interaction with observable phenomena.

Hands-on activities designed by Unal (2008) show that the instruction has a significant positive effect on students' understanding of flotation concepts and rules. Regarding the results, students indicated a clear increase in understanding of flotation. As an example, 50% of students thought that when a floating object was cut into two parts, the volume of the sinking part of the smaller

piece would become less. However, only 18% of the students possessed these misconceptions on the post-test. Proposed instruction by Bessas et al. (2024) shows that the method successfully addressed and corrected students' initial misconceptions, with improvement rates ranging from 18.08% to 52.13% depending on the indicator of misconceptions. Such interventions provide concrete experiences that reinforce the understanding of density, buoyant force, and fluid properties through direct interaction with observable phenomena.

There are 52 studies that implemented conceptual change approaches, such as cognitive conflict to address misconceptions (Skoumios, 2009) and instructional remediation targeting long-term conceptual restructuring (Gao et al., 2021). These approaches emphasize conceptual restructuring, in which learners' initial ideas are confronted with discrepant events or conflicting evidence.

Figure 3 illustrates that research on teaching static fluid concepts employs a wide range of instructional models and approaches oriented toward knowledge construction and conceptual change. Each model emphasizes different strategies for addressing misconceptions, strengthening conceptual understanding, and fostering learners' scientific reasoning skills.

There are 17 studies employed computer-based learning interventions using digital media, computer simulations, or virtual laboratories. These include virtual simulations to reduce fluid-related misconceptions (Saputra, 2022) and computer simulations via the CoSci platform (Wongsuwan et al., 2021). Digital media support instruction by enabling the visualization of abstract phenomena (density, pressure, buoyant force) through animations, visual models, and interactive variable manipulation.

There are 18 studies related to interventions that cannot be categorized into the four studies. An example of this line is research by Jackson (2021).

Only one article explicitly used the keyword mental model in connection with an intervention design, namely the study by Taher et al. (2017). This study specifically aimed to develop students' mental models of Archimedes' principle through a multi-representation approach.

Advanced analysis of the various instructional interventions on FSS concepts shows five studies explicitly related to interventions aimed at addressing student misconceptions and mental models. Each intervention is designed with the shared goal of helping learners navigate the complex relationships among density, buoyant force, and object behavior in fluids. While each approach demonstrates distinct characteristics and varying degrees of effectiveness, they

complement one another in efforts to enhance the quality of science learning.

Viewed collectively, these findings indicate that no single instructional approach functions as a universal solution. Technology-based interventions offer powerful visualization capabilities, structured instructional models provide a solid framework for conceptual progression, hands-on activities supply essential foundational experiences, and cognitive mechanisms such as conceptual conflict act as catalysts for conceptual change. Together, these four categories of interventions form a comprehensive pedagogical landscape for addressing misconceptions and promoting the development of deeper, more scientific mental models.

Guided instructional approaches significantly reduce student misconceptions in physics, particularly in static fluid topics, by explicitly engaging and restructuring students' existing cognitive frameworks. Multiple Indonesian studies provide strong evidence for this claim. Maknun et al. (2022) showed the Conceptual Change Model reduced student misconceptions. Verawahyuni (2022) demonstrated that laboratory-based guided inquiry successfully decreased misconceptions across learning cycles. Several studies further confirmed the Predict-Observe-Explain (POE) model's effectiveness in remediating misconceptions in static fluid concepts.

The studies on static fluids demonstrate that misconceptions, mental models, assessment, and learning interventions are deeply interconnected dimensions of students' conceptual systems, requiring an integrated research approach. For instance, Sarini et al. (2022) found that misconceptions in static fluids occur across multiple concepts like hydrostatic pressure and Archimedes' principle. Ginting et al. (2023) developed diagnostic tests revealing that students' conceptual understanding varies significantly, with 11.92% showing misconceptions and 32.02% not fully comprehending the concepts.

The research emphasizes that effective science education must holistically examine how understanding develops. Several studies identified specific misconceptions students hold, such as misunderstanding how pressure and buoyancy work, underscoring the need for integrated, multidimensional approaches to conceptual learning.

In the case of FSS phenomena, such integration is particularly critical because learners' reasoning is strongly influenced by everyday experiences that appear intuitively compelling. Without explicit attention to mental models and diagnostic assessment, instructional interventions risk producing short-term performance gains without deep conceptual restructuring. Therefore, future research should prioritize design-based

approaches that simultaneously investigate learning processes, instructional supports, and changes in learners' mental models over time. Schwichow et al. (2024) further show that interventions can achieve large effect sizes in improving conceptual understanding, especially when using hands-on experiments and longer-duration interventions. From this perspective, the prevalence of intervention studies may also be interpreted as attempts to scaffold learners' progression from intuitive reasoning toward more coherent density-based explanations. This reinforces the argument that research on FSS phenomena should be analyzed not only in terms of instructional effectiveness, but also in relation to the cognitive trajectories learners follow across grade levels. In addition, assessment practices should be developed not only to evaluate learning outcomes, but also to reveal students' reasoning patterns and the progression of their mental models, thereby supporting the development of deeper and more sustainable scientific understanding of FSS phenomena.

## Conclusion

This SLR synthesized research on misconceptions and mental models related to FSS concepts published between 1990 and 2025 and included in the Scopus database. The findings show that misconceptions were still an investigated aspect by researchers, indicating enduring difficulties among learners in understanding density, volume, buoyant force, and their interrelationships. These challenges highlight the abstract nature of FSS concepts and the need for instructional designs that effectively confront and reconstruct learners' intuitive ideas. Studies on mental models (explicitly) are still scarce, but there are seven or more studies if they are combined with misconception and instrument development to explore them. The studies revealed that learners often rely on context-dependent initial or synthetic models, with only gradual progression toward scientific reasoning. A range of instructional interventions has been implemented, including hands-on activities, computer-based simulations, conceptual-change approaches, and structured learning models. While each offers distinct strengths, the review indicates that no single intervention is sufficient. Instead, effective FSS instruction benefits from integrating experiential learning, conceptual scaffolding, visualization tools, and cognitive conflict to foster deeper scientific understanding. This review emphasizes the need for more balanced research that simultaneously addresses misconceptions, mental models, reasoning, and assessment. Strengthening interventions will support deeper insights into learners' scientific understanding of

FSS concepts. A key practical implication is that instruction on floating, suspending, and sinking concepts should be designed in an integrative manner and oriented toward the reconstruction of learners' conceptual understanding. As a practical implication, educators need to explicitly identify and utilize students' misconceptions and initial mental models as entry points for instruction, and then guide their development through cognitive conflict, conceptual scaffolding, and the use of multiple representations. Teaching practices should combine hands-on experimental experiences with technology-based visualizations and simulations, as well as conceptual-change approaches, to help learners connect empirical phenomena with abstract concepts such as density, volume, and buoyant force.

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## Author Contributions

Conceptualization, S.N.K., S.S. and A.A.; methodology, S.N.K., C.D. and S.S.; formal analysis, S.N.K., N.P.M., N.H. and S.S.; resources, S.S. and A.A.; data curation, S.N.K., N.P.M., N.H.; writing—original draft preparation, S.N.K.; writing—review and editing, S.N.K. and S.S., and A.A.; visualization, A.A. All authors have read and agreed to the published version of the manuscript.

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The authors declare no conflict of interest.

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