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PAPER

# Inquiring Students' Alternative Conceptions about Floating and Sinking Objects

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## ABSTRACT

The aim of this study is to determine the misconceptions of Greek junior high school students regarding the floating and sinking of a body through the concept of density. Density is included in most international curricula for this age group and is revisited in Greek junior high schools after being introduced in primary school. After interviews with teachers who teach the physics course, in order to discover the students' way of thinking and their common misconceptions, the researchers of this study created targeted questionnaires for students aged 11–12 years old. During the 2022–23 school year, the questionnaires were handed out to 47 first-grade students at a junior high school in Athens, Greece. Before being administered to the students, the questionnaires were subjected to a content validity test by five physics experts according to Aiken's V index. Then, they were completed by the students before the lesson was taught. After the students had completed the initial questionnaire, a teaching proposal focused on the density-based approach was presented to them. Subsequently, the students filled out the same questionnaire again following the instructional session. Statistical analysis demonstrated a notable enhancement in the comprehension of the misconceptions addressed in this study, with the rates of improvement varying between 18.08% and 52.13%. Consequently, the instructional proposal proved to be instrumental in advancing students' conceptual understanding of floating and sinking within the framework of density interpretation.

## KEYWORDS

floating, sinking, density, misconceptions, junior high school

## 1 INTRODUCTION

One of the basic, but at the same time challenging, issues that are encountered internationally in the physics curricula is the floating and sinking of bodies [1]. Due to their everyday experiences, many students have developed an understanding of when a body floats or sinks [2, 3]. From the stone tossed into the calm waters of a lake to the boat floating, to the sun balloon rising high in the sky, to the coin that ends up at the bottom of a fountain. From the ice cube floating in the glass of their favorite

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soda and the straw that sinks into it. However, these pre-existing ideas on the issue of floating and sinking often conflict with the scientific standard [4]. Students often diverge from the scientific standard in understanding floating and sinking phenomena by relying on perceptual cues and macroscopic properties, such as size and weight, rather than on the underlying principles of density and buoyancy. Students struggle with the abstract concept of density as a ratio of mass to volume and fail to appreciate the relational reasoning required to compare object and fluid densities accurately. Additionally, they tend to use linear reasoning, focusing on the object’s visible characteristics and position relative to the fluid surface, and often confuse buoyancy as an intrinsic property of the object rather than a force resulting from fluid displacement. This perceptual and reasoning gap hinders their ability to apply the scientific explanatory model effectively [1, 2, 4].

Students in Greece first encounter the density concept in the later grades of primary school and the early grades of junior high school [5, 6]. Therefore, an attempt is made to include floating and sinking phenomena in the context of physics courses [7], primarily for primary school students, as an application to density issues [8, 9]. With our work, we extend the incorporation of the application of floating and sinking bodies to junior high school students since it is not typically taught in the Greek junior high school physics course. Incorporating the study of floating and sinking bodies into the junior high school curriculum enhances students’ understanding of fundamental physics concepts such as density, buoyancy, and fluid mechanics. By exploring these phenomena in greater depth, students develop critical thinking and analytical skills, moving beyond simplistic, perceptual explanations to grasp the underlying scientific principles. Additionally, understanding these principles can have practical implications, enhancing students’ ability to relate classroom knowledge to real-world situations.

With our study, implementing a density-based teaching strategy for floating and sinking phenomena will significantly enhance junior high school students’ comprehension and correct their misconceptions about these concepts. This approach capitalizes on students’ ability to grasp the mathematical formulation of density through hands-on experiments and observations. Alongside the previous, it allows students to see the direct engagement between the mass and volume of different materials, making it a concrete and manipulable concept. Thus, students will develop a deeper understanding of how these factors influence whether objects float or sink. This method not only clarifies the principles of density but also encourages critical thinking and scientific inquiry, ultimately leading to a more robust and accurate understanding of physical science.

This paper serves a dual purpose. Firstly, it aims to identify and emphasize the misconceptions among Greek junior high school students regarding the understanding of floating phenomena, specifically from the perspective of the density concept. Secondly, it demonstrates how significantly students’ performance improved following the implementation of the proposed teaching strategy. We chose the density-based approach as we believe that for the knowledge level of junior high school students, it is easier to accept.

In Greece, junior high school students encounter the mathematical formulation of the concept of density for the first time. Through direct experiments and observations, they can easily calculate the value of density. Thus, they can easily compare the density values of different materials and draw conclusions regarding whether an object will float or sink.

Teaching density through hands-on activities and visual demonstrations can help students move beyond perceptual reasoning to a more analytical understanding of why objects float or sink [1, 7–9].

In Greece, while there have been several studies focusing on students’ misconceptions regarding floating phenomena and teaching approaches to this issue through the lens of density, these studies primarily targeted elementary school students rather than junior high school students [1, 7–9].

According to existing literature, no relevant studies have been conducted before at the junior high school level as in the framework described below. Our study aims to fill this gap by focusing on junior high school students and examining their misconceptions in the context of density-based teaching. This is particularly important as junior high school students are at a critical stage in their scientific education, where a deeper understanding of fundamental concepts can significantly impact their future learning. Therefore, the present study implements a teaching proposal and uses a targeted questionnaire to identify students' misconceptions. The questionnaire was distributed to 47 first-grade students at a junior high school in Athens during the 2022–23 school year, both before and after implementing the teaching proposal.

## 2 LITERATURE REVIEW

### 2.1 Alternative conceptions and conceptual change

Before they even arrive in the classroom, students have certain conceptions, either intuitive or from their everyday experience [10]. These conceptions, often referred to in the literature as "alternative ideas," "alternative conceptions," "alternative context," "misconceptions," "children's science," and "naïve views" [11, 12, 13, 14], oppose scientific knowledge [15, 16]. The term most frequently employed is "misconception," meaning the inconsistency with the scientific concepts. In fact, these misconceptions are profoundly entrenched because students see them validated by their experiences in the natural world, making them resistant to conceptual change. By the term "conceptual change," we refer to the process of restructuring students' alternative notions on specific topics and shifting their understanding toward scientific truth [17].

Thus, students tend to interpret any future phenomenon with which they come into contact with their prior knowledge [13]. Indeed, the process of conceptual change is not a spontaneous and lightning-fast transition from initial and naive ideas to the scientific paradigm, but a process that requires time and specific guidance strategies to achieve [17].

Students tend to remember more things from personal experience than from something they have read. However, when students are not confronted with situations where their perceptions cannot explain the phenomena, these perceptions become entrenched, and the process of deconstructing them is not easy [4]. Research by Vosniadou supports this, indicating that students' mental models are robust and resistant to change unless they experience cognitive conflict. The teacher must, therefore, create conditions in which conceptual change can be achieved. This involves designing instructional strategies that challenge students' existing misconceptions and encourage them to re-evaluate their understanding [10, 17].

There are many times, however, when students, without having fully understood the concepts they encounter in the classroom, without rejecting their own ideas, accept the school knowledge, thus maintaining two perceptions of the same concept [18, 19]. The school knowledge provided by the teacher has a boundary in the classroom. The student appreciates that this knowledge refers only to the level of examination and assessment. Therefore, addressing students' misconceptions is essential and plays a significant role in effective science instruction.

Since the late 1970s and early 1980s [13, 20, 21, 22, 23, 24, 25] there has been a shift towards the recognition of students' misconceptions. Even today, however, few teachers seek them out and take them into account in their lesson planning and teaching techniques [15]. According to Hammer, misconceptions may also be held by teachers. In any case, however, wherever the misconception comes from, it significantly affects the acquisition of new knowledge and is difficult to change. It is important, therefore, to recognize it early and overcome it so that the new knowledge can be built on a solid foundation [15, 16]. To unlearn in an orderly manner through specially designed teachings that include misconceptions, what does not agree with scientific knowledge [26].

## 2.2 Misconceptions in the floating and sinking phenomenon

Constructivism posits that learners construct new understandings based on what they already know. Therefore, recognizing and incorporating students' pre-existing ideas helps create a bridge between prior knowledge and new concepts, making learning more meaningful and effective [27]. On the basis of a constructivist approach, it is crucial that students' pre-existing ideas are taken into account and included in the design and implementation of instruction. By identifying these pre-existing ideas, educators can design instruction that directly addresses and corrects misconceptions. This process is essential for conceptual change, where students replace their incorrect understandings with scientifically accurate concepts [10, 17, 20, 21].

Students' difficulties with floating and sinking are primarily due to their lack of understanding of the concept of density and vice versa [8]. The difficulty encountered by students is more qualitative than quantitative in nature [9]. The pre-existing mental models that students have constructed from their everyday experience conflict with scientific data [4]. There is confusion between the concepts of mass, volume, and density, with no clear separation and differentiation between them [8, 9, 28, 29].

Several students tend to interpret the phenomenon in terms of the mass or weight of a body, considering that a heavy body necessarily sinks. Similarly, bodies of large dimensions are also considered to be necessarily sinking by a portion of students [9, 28, 30, 31, 32, 33, 34, 35, 36, 37, 38]. In some cases, students include parameters such as the dimensions of the container in which the body is immersed, the amount of liquid, and even the height of the liquid in the container in their interpretation of the phenomenon [1].

The occurrence of cavities and the amount of air in a body, or whether it is perfectly solid, is something that students often confuse in their judgment of whether the body will eventually sink or float [1, 2, 30]. What students lack is combinatorial thinking, as they focus individually on either the body or the liquid and their properties, failing to connect them together [8, 28, 39].

Students often fail to understand even the words "floating" and "sinking" and their relationship in terms of physics terminology. According to Joung [40], students, having a confused view, judge the floating or sinking of a body according to the relative position of the body with respect to the liquid in which it is submerged. Thus, a body can float as long as part of the body is outside the liquid or even below the surface of the liquid, half-submerged. According to Joung's research [40], students generally perceive a body to be submerged if it is either in the middle of the liquid in a container or at the bottom, without making any distinction between these positions.

The purpose of this study, therefore, is to find out junior high school students' misconceptions on this issue. Are there, perhaps, practical ways through teaching to address students' difficulties and overcome them in the context of conceptual change [26]?

## 2.3 Explanatory models in floating and sinking phenomenon

Approaching the phenomenon of floating and sinking bodies is a challenge for students, as its explanation relies on understanding difficult concepts such as density and buoyancy [7]. Thus, according to the existing literature, its interpretation is based on two different explanatory models.

**Density-based model.** The first model that teachers follow for introducing floating phenomena is the so-called density-based method. The density-based method, often introduced in primary and junior high schools, utilizes the elimination of variables approach [7]. In this kind of approach, through density, one will find the mathematical definition of density as the ratio of mass per volume $\left(\rho = \frac{m}{V}\right)$ [31, 32], the particle theory of matter [41], and even visual representations that focus on the qualitative aspect of density [6, 7, 8]. However, the abstract nature of the density concept appears to complicate learning for students [8, 9, 33, 34, 42], as it requires them to perform mathematical calculations [8, 43]. Nevertheless, students for concluding whether a body floats or sinks only have to compare the density of the body with the density of the fluid in which it is immersed [39]. If the density of the body is greater than the density of the liquid in which it is immersed, then the body sinks and vice versa. This approach focuses on constructing predictive models to determine whether an object will float, which is simpler and more accessible for younger students.

**Buoyancy-based model.** The second model science educators use to explain the phenomenon is the buoyancy-based method [44]. Typically adopted in higher education, it employs a scientific approach, analyzing equilibrium to explain how objects float. This method integrates more complex concepts such as the balance of buoyancy and gravity forces, making it a more potent but challenging model. The difficulty that arises in this kind of approach is that students should have an understanding of Newtonian mechanics, which refers to the concept of forces and fluid pressure. They must therefore enter the process of comparing the forces of weight and buoyancy [30, 45]. Buoyancy is a core concept in fluid mechanics, elucidating why objects float or sink. It is intricately linked to Archimedes' Principle. This principle asserts that any object, either completely or partially submerged in a fluid, experiences an upward force known as the buoyant force. This force is equivalent to the weight of the fluid that the object displaces. Essentially, the buoyant force acts against the weight of the displaced fluid, determining whether an object will float or sink. An object floats if the buoyant force is greater than the object's weight, while it sinks when the object's weight exceeds the buoyant force [1, 3, 7, 44].

Thus, the phenomenon of floating and sinking bodies is considered ideal for teaching the concept of density [33, 35]. In fact, the concept of density is preferred to explain the floating and sinking phenomenon to junior high school students, while buoyancy interprets the phenomenon in high school and university [6, 7, 27]. This is the reason why we opted for the density-based model to explore the phenomena of floating and sinking.

Obviously, each of the above-mentioned models, the density-based and the buoyancy-based ones, needs its own careful way of design and implementation to be effective during teaching.

## 2.4 The impact of experiments in physics lessons

In a modern analytic curriculum, as envisioned by Driver and Oldham [13], based on conceptual change through the constructivist model of teaching [20, 21], learning is not only the transfer and acquisition of knowledge but, above all, interaction with what is already known [46].

Studies have shown that active student participation in the teaching process, particularly in science and mathematics, is more effective in bringing about conceptual change compared to traditional teaching methods [47]. McDermott underscores the significance of reducing strict mathematical formalism and concentrating on qualitative questions to better grasp concepts. Experiments are deemed vital in education, with an emphasis on students performing these experiments individually or in small groups. This hands-on method often leads to discoveries that defy initial expectations, generating cognitive conflict that promotes conceptual change [48, 49, 50, 51].

Hatano and Inagaki, building on Itakura's Hypothesis-Experiment-Instruction method, found that using multiple-choice questionnaires with common misconceptions as possible answers effectively induces cognitive conflict. This method encourages students to re-evaluate their initial beliefs and engage in collaborative discussions, which often lead to conceptual change [52, 53, 54, 55, 56].

The predict-observe-explain (POE) method, proposed by White and Gunstone, also supports the view that experimentation precedes conceptual change in physics education. This method involves students making predictions about experimental outcomes, observing the actual results, and then explaining the discrepancies between their expectations and the observed outcomes. This process creates cognitive conflict, prompting students to recognize the need for conceptual change because their initial mental models fail to explain the observed phenomena adequately [4, 50, 51, 57].

In general, hands-on activities are preferred compared to the traditional way of teaching, as they enhance creative engagement and stimulate students' interest [58]. Guided experiments seem to be more accepted and result in more meaningful outcomes that lead effortlessly to conceptual change [3, 7, 59].

The proposed teaching on the phenomenon of floating or sinking a body, presented below, is based on this experimental approach. It is a mixture that combines frontal teaching and hands-on activities for students by performing targeted experiments according to the work of Schwichow and Zoupidis [7]. This proposed method, by employing the POE strategy, creates cognitive conflict to facilitate conceptual change.

The role of the teacher, therefore, in such a model, is to take into account the students' misconceptions and to lead the students with appropriate manipulation and methodicalness to the cognitive conflict [2, 60].

## 3 METHODS

### 3.1 Context

Are students' intuitive perceptions or experiences always consistent with scientific knowledge? Is there agreement or divergence with scientific data that leads to misconceptions?

In discussions with teachers who teach physics in Greek junior high schools, researchers found that one of the issues that students, both during instruction and assessment, often seem to have difficulty with is whether a body floats or sinks. Indeed, they often refrain from addressing the issue in terms of density. Through the proposed teaching plan presented below, a correlation between the concept of density and floating and sinking phenomena is attempted.

A review of international literature reveals that findings from various articles align with the views of Greek teachers who instruct physics courses [1, 2, 3, 7, 30]. Consequently, this study seeks to identify and highlight the misconceptions of Greek junior high school students concerning the phenomenon of floating and sinking, analyzing the issue from the perspective of density. In fact, the study is extended to junior high school students, something that has not been done in Greece before in the form we envision.

The implementation of the proposed teaching approach and the subsequent study took place within the framework of the physics course in the science laboratory of a junior high school in Athens, Greece, during the 2022–2023 school year. It involved first-grade junior high school students and was conducted during the period when the corresponding unit on density was being taught, according to the curriculum.

## 3.2 Design and participants

For this purpose, the tool that was used to identify students' alternative ideas was a multiple-choice questionnaire. Each question presented a scenario involving sinking and floating and asked students to predict the outcome. A student with a scientifically accurate understanding is more likely to predict correctly, whereas one with misconceptions is more likely to predict incorrectly [30].

The questionnaire was distributed to a sample of 47 first-grade students of a junior high school in Athens, Greece, during the school year 2022–23. There was no criterion for selecting students. All students without exception who were attending the first grade of a junior high school in Athens in the 2022–23 school year were selected, and in fact there was no one who did not accept participation in the survey.

All students volunteered to participate in the study, which had initially been approved by the school's administration. The questionnaire was completed after the consent of the students' guardians and after approval by the Ethics department of the University of Thessaly.

The purpose of the survey was communicated to the students to highlight specific misconceptions in their understanding of floating and sinking phenomena. They were informed that in no way was the questionnaire a criterion for their assessment at school, nor would it affect their grade in physics. The sole aim was to improve the teaching strategy for physics lessons at junior high school. Undoubtedly, the questionnaires were completed anonymously by the students; the results were only for the researchers and would not be disclosed to anyone else.

### Process of constructing a tool to diagnose students' misconceptions

***Analysis.*** The approach for constructing a reliable and valid tool to diagnose students' misconceptions on floating phenomena is a five-step process. Firstly, the researchers, guided by the syllabuses for the physics courses in secondary school, contacted the educational community and discussed with junior high school physics teachers the problems faced by students in the subject. A literature search was carried out on similar studies that have been done, and it was found that floating and sinking is one of the subjects where relative difficulty is shown by students [2, 30, 35, 36, 38, 43]. Their specific misconceptions were identified. Through the dialogue with teachers, the frequently occurring misconceptions of students that were present in the literature review section (refer to section 2.2) were verified, and others were suggested.

***Design.*** This was followed by meticulous handling of the information and thoughtful development of the questionnaire. The questions were designed to emphasize students' misconceptions, as identified through previous discussions and literature reviews.

Table 1, according to each question, shows the indicator—students' misconceptions, thus revealing the purpose of each question.

**Table 1.** Categorization of questions according to the indicator-misconception to be highlighted

| Questions | Indicator-Misconception Sought to be Highlighted |
|---|---|
| 1 | The aim is to find out whether students consider the mass or volume of a body to be responsible for floating or sinking |
| 2 | |
| 3 | |
| 4 | |
| 5 | |
| 6 | |
| 7 | |
| 8 | The aim is to find out whether students consider the surface of a body to be responsible for its floating or sinking |
| 9 | |
| 10 | The aim is to find out whether students think that hollow bodies necessarily float |
| 11 | |
| 12 | |
| 13 | |
| 14 | The aim is to find out whether students think that the amount of liquid in the container affects floating or sinking |
| 15 | |

Table 2 shows the explanation for the groups of questions and what the researchers' rationale is for each question in a detailed manner.

**Table 2.** Analytically questions' description according to the indicator-misconception to be highlighted

| Questions | Questions' Rationale |
|---|---|
| 1 | These questions involve scenarios where students need to determine the outcome related to different liquids in terms of which will be at the bottom or top in various containers. The aim is to assess if students attribute floating or sinking to the mass or volume of the liquids. |
| 2 | |
| 3 | |
| 4 | These questions are about predicting the behavior of cubes in water, considering their dimensions or mass relative to another cube. Question 7 examines how increase of a liquid affects the condition described in the corresponding figure. The aim is to identify if students consider volume as the critical factor for an object's ability to float or sink. |
| 5 | |
| 6 | |
| 7 | |
| 8 | Students are asked to predict the outcome when a cube that normally sinks is cut in half and placed on the surface of the liquid. This question evaluates whether students think the change in surface area (due to being cut in half) will affect the object's behavior. |
| 9 | Involves a copper cube and a copper sheet in water, testing whether students believe that the shape or surface area of the same material influences floating or sinking. |
| 10 | Each question presents a scenario with a solid and a hollow cube, asking students to predict which cube floats or sinks. These questions aim to discover whether students automatically assume that hollow bodies will float regardless of other factors like material or dimensions. |
| 11 | |
| 12 | |
| 13 | |
| 14 | Explores if students believe that changing the water level (by reducing it to half) in the container affects the phenomenon. |
| 15 | Asks whether increasing the amount of water in the container influences the phenomenon, testing students' understanding of how the volume of liquid impacts floating or sinking. |

***Development.*** Then, at the development stage, the constructed questionnaire was distributed to five evaluators—experts, all of them junior high school physics teachers with at least ten years of teaching experience in the specific unit—in order to determine the degree of validity of its content. Thus, another questionnaire with five possible choices of an ordered scale from "Strongly Disagree" corresponding to 1 to "Strongly Agree" corresponding to 5, based on the Likert scale, was given so that the experts could judge each question of the students' questionnaire individually according to specific criteria (Strongly Disagree: 1, Disagree: 2, Neutral: 3, Agree: 4, Strongly Agree: 5). The specific criteria are shown in Table 3.

**Table 3.** Questionnaire's validity criteria

| No. | Criteria |
|---|---|
| 1 | Clear scientific questions' structure |
| 2 | Clear scientific structure of answers |
| 3 | Questions suitable for identifying students' alternative ideas |
| 4 | The questions are not ambiguous and confusing |
| 5 | Achievement of the objective of the questionnaire |
| 6 | Simple and understandable questionnaire language |

The degree of validity of the questionnaire, depending on the experts' responses, is calculated according to Aiken's equation from the index:

$$V = \frac{\sum_{1}^{n} s}{N(c-1)} \tag{1}$$

where $s$ is the difference between the smallest Likert scale value and each expert's score for that question, $N$, the number of experts evaluating the questionnaire and $c$, the maximum number on the Likert scale [42], [43].

The $V$ index ranges from 0 to 1, with 1 being the most valid questionnaire.

According to the questionnaire's validity criteria table, the five experts came to the conclusions shown in Table 4.

**Table 4.** Expert responses to the questionnaire validity test for each question based on the criteria provided in Table 3

| Questions | Specialist 1 | Specialist 2 | Specialist 3 | Specialist 4 | Specialist 5 |
|---|---|---|---|---|---|
| 1 | 4 | 5 | 4 | 5 | 5 |
| 2 | 5 | 4 | 5 | 4 | 4 |
| 3 | 5 | 5 | 5 | 5 | 5 |
| 4 | 5 | 5 | 4 | 5 | 5 |
| 5 | 3 | 5 | 4 | 4 | 5 |
| 6 | 4 | 4 | 5 | 4 | 5 |
| 7 | 5 | 4 | 4 | 4 | 4 |
| 8 | 5 | 3 | 4 | 5 | 4 |
| 9 | 4 | 3 | 5 | 5 | 5 |
| 10 | 5 | 5 | 5 | 3 | 3 |
| 11 | 4 | 5 | 4 | 4 | 5 |
| 12 | 4 | 5 | 5 | 3 | 4 |
| 13 | 5 | 5 | 4 | 4 | 4 |
| 14 | 5 | 4 | 3 | 4 | 5 |
| 15 | 5 | 4 | 5 | 5 | 4 |

According to equation (1), by calculating the Aiken's V index for each question [42], [43], we obtain the results shown in Table 5.

**Table 5.** Aiken's V-index for each question of the student questionnaire, according to the criteria provided in Table 3

| Questions | Aiken Validity Index V | Validity of Questions |
|---|---|---|
| 1 | 0.9 | Valid |
| 2 | 0.85 | Valid |
| 3 | 1 | Valid |
| 4 | 0.95 | Valid |
| 5 | 0.8 | Valid |
| 6 | 0.85 | Valid |
| 7 | 0.8 | Valid |
| 8 | 0.8 | Valid |
| 9 | 0.85 | Valid |
| 10 | 0.8 | Valid |
| 11 | 0.85 | Valid |
| 12 | 0.8 | Valid |
| 13 | 0.85 | Valid |
| 14 | 0.8 | Valid |
| 15 | 0.9 | Valid |

In his articles [61, 62], Aiken determined that a V coefficient of 0.8 was necessary for a questionnaire to be deemed valid. This involved using a five-point Likert scale and having five experts review the questionnaire. Thus, each criterion meets Aiken's required V factor, making the entire questionnaire sufficient for use. Consequently, the results derived from the students' responses are considered reliable for analysis.

Expanding on the analysis, Aiken's method ensures that the questionnaire not only aligns with expert consensus but also achieves a high level of validity. The V coefficient of 0.8 suggests a strong agreement among experts, which supports the instrument's capability to accurately capture the intended data. This level of validation is crucial for interpreting the students' misconceptions effectively, providing a solid foundation for subsequent educational interventions or research.

*Implementation.* The subsequent phase, the implementation stage, entailed handing out the questionnaire to students and having them fill it out within one teaching hour prior to the scheduled lesson. Following this, a lesson was carried out according to the teaching proposal outlined below. Afterward, in the next teaching hour, the students were asked to complete the questionnaire once again.

*Evaluation.* The process was concluded by statistically analyzing the questionnaires before and after teaching the subject matter and assessing whether the proposed approach, from a teaching point of view, benefited the students or not. This entire process, as discussed above, is summarized in Figure 1.

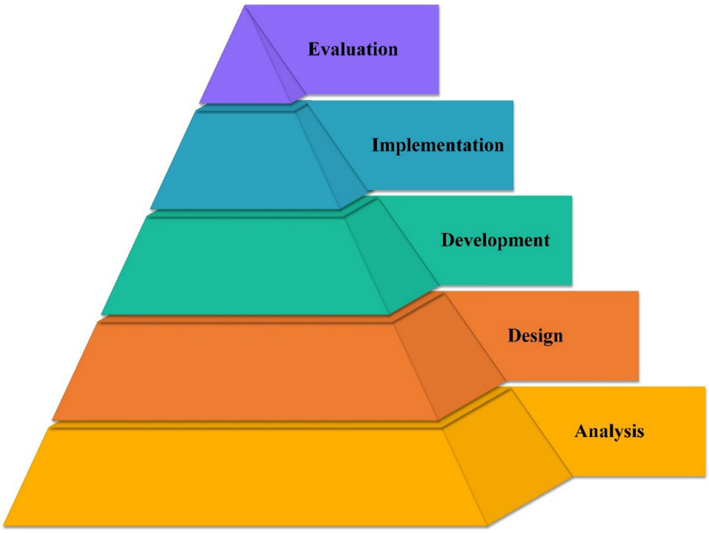

**Fig. 1.** Process of constructing a tool to diagnose students' misconceptions

### 3.3 Data collection techniques

The questionnaire contains 15 multiple-choice closed-type questions related to the subject studied by the students. The questions and possible answers were formulated in such a way that it was easy to highlight any misconceptions of the students, in line with previous research [31, 32, 34, 36, 37]. The 47 students in the sample filled out the questionnaire both before and after the teaching session was conducted. The students' responses were inputted into SPSS version 25, which was utilized for the statistical analysis.

**Density questionnaire.** This subsection presents the 15 questions included in the questionnaire, which aimed to evaluate the students' initial beliefs and the effectiveness of the proposed teaching approach in fostering conceptual change.

**Q1.** Place three containers on the following electronic scales, and after zeroing their readings, fill the three containers with three different liquids, as shown below. Then carefully empty the contents of the containers into a new container. Provided that the three liquids do not mix with each other, find the order of the liquids in the new container, starting from the bottom of the container.

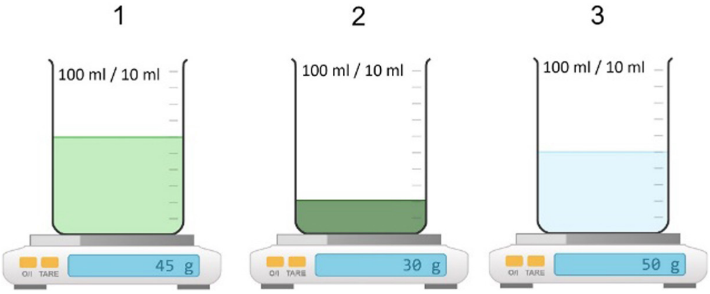

**Fig. 2.**

**A.** 1, 3, 2
**B.** 3, 1, 2
**C.** 2, 3, 1
**D.** we cannot know

**Q2.** The figure below shows two identical volumetric cylinders containing two different liquids:

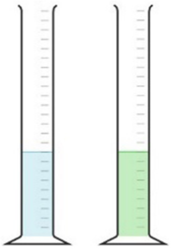

Fig. 3.

If we empty their contents into transparent identical bottles and place them on the two arms of a comparison balance, looking carefully at the shapes, choose which of the shapes A, B, or C corresponds to reality:

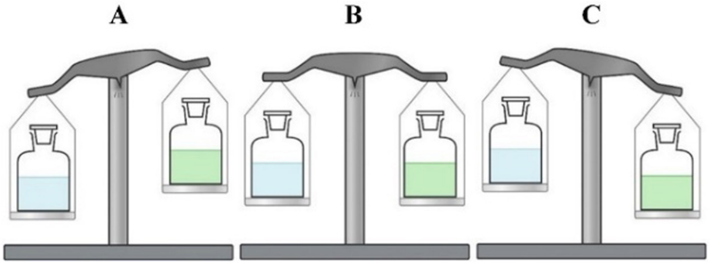

Fig. 4.

**A.** A
**B.** B
**C.** C
**D.** we cannot know

**Q3.** Two identical volumetric cylinders contain two different liquids, A and B, respectively.

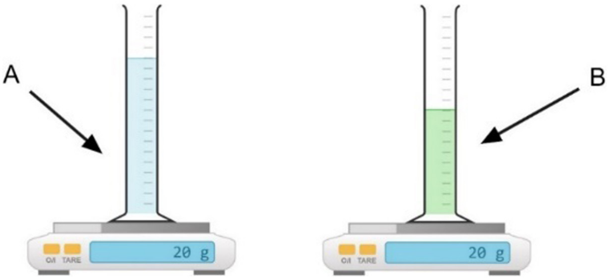

Fig. 5.

Looking carefully at the figure, if we place the contents of two volumetric cylinders in a beaker, assuming that the liquids do not mix, which one will be at the bottom of the beaker?

**A.** The A
**B.** The B
**C.** We cannot know

**Q4.** Given two cubes A and B, respectively, which have the same dimensions.

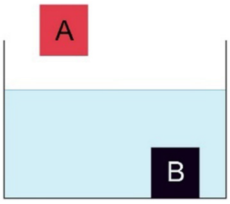

Fig. 6.

When B is submerged in water, then A:
**A.** Sinks
**B.** Floats
**C.** We cannot know

**Q5.** Given two cubes A and B, respectively, which have the same mass.

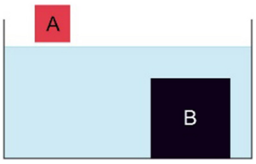

Fig. 7.

When B is submerged in water, then A:
**A.** Floats
**B.** Sinks
**C.** We cannot know

**Q6.** A cube A floats in a container of water. Cube B in the figure, made of the same material, is left on the surface of the water in the same container.

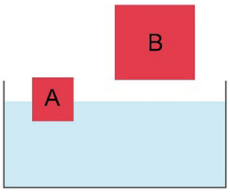

Fig. 8.

Then, cube B:
**A.** Sinks
**B.** Floats
**C.** We cannot know

**Q7.** The volumetric cylinder shows two liquids 1 and 2 that do not mix.

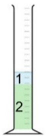

Fig. 9.

If we add a quantity of liquid 1 so that its quantity exceeds the quantity of liquid 2, then liquid 1:

**A.** Sinks
**B.** Floats

**Q8.** A cube sinks into a liquid. If we cut the cube in half and leave it on the surface of the same liquid, then:

Fig. 10.

**A.** The piece sinks
**B.** The piece floats
**C.** We cannot know

**Q9.** A copper cube is immersed in a container of water, as shown in the figure. A copper sheet is left on the surface of the same container.

Fig. 11.

Then, the copper sheet:
**A.** Sinks
**B.** Floats
**C.** We cannot know

**Q10.** Two cubes A and B, made of different materials, have the same dimensions and the same mass. Cube A is solid, while cube B is hollow. Hollow cube B floats in a container of water.

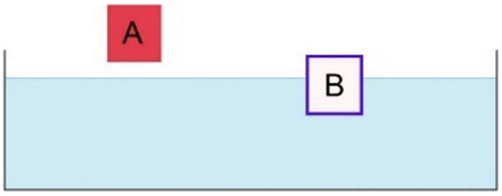

Fig. 12.

Then, the solid cube A:
**A.** Sinks
**B.** Floats
**C.** We cannot know

**Q11.** Two cubes A and B, made of different materials, have the same dimensions. Cube A is solid, while cube B is hollow. The mass of cube B is greater than the mass of cube A. Hollow cube B is barely submerged in a container of water.

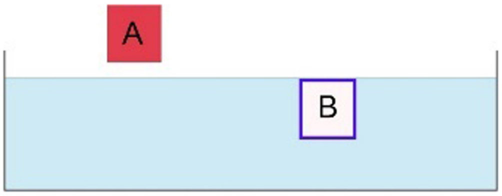

Fig. 13.

Then, the solid cube A:
**A.** Sinks
**B.** Floats
**C.** We cannot know

**Q12.** Two cubes A and B, made of different materials, have the same dimensions and the same mass. Cube A is solid, while cube B is hollow. Cube A, which is solid, is immersed in a container of water.

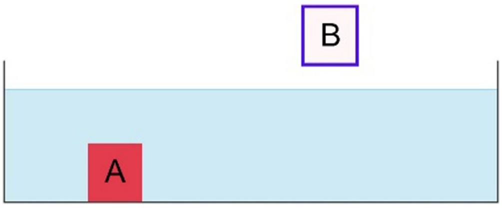

Fig. 14.

Then, cube B:
**A.** Sinks
**B.** Floats
**C.** We cannot know

**Q13.** A solid metal cube is immersed in a container of water. If a cylindrical piece is removed from the same cube, as shown in the figure below.

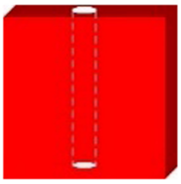

Fig. 15.

Then the cube:
**A.** Sinks
**B.** Floats
**C.** We cannot know

**Q14.** A cube floats in a container of water.

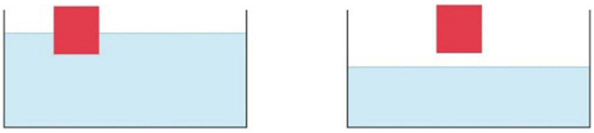

Fig. 16.

If the container is filled with half the amount of water, then the cube:
**A.** Sinks
**B.** Floats
**C.** We cannot know

**Q15.** A cube is submerged in a container of water.

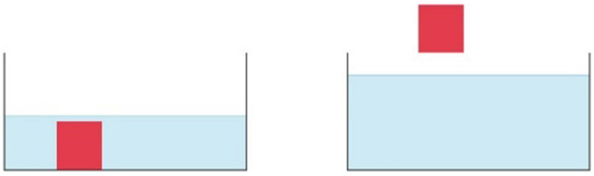

Fig. 17.

If the amount of water in the container increases, then the cube:
**A.** Sinks
**B.** Floats
**C.** We cannot know

## 4 TEACHING PROPOSALS

While the questionnaire had already been completed by the sample of students, a specific teaching proposal based on the density-based approach was then proposed. According to Section 2.4 and the conclusions reached regarding the positive impacts of experimentation on the teaching of physics, the teaching proposal was based on the experimental method while avoiding mathematical formalism. It consisted of four separate activities related to density measurement. Through the experimental procedures described, the concept of density was related to floating and sinking phenomena. These procedures were suitably designed to prompt students, in the context of conceptual change, to revise any misconceptions they may have had.

### 4.1 Activity 1

Students were introduced to the concept of density with a brief explanation, emphasizing that density is a physical property of materials. The mathematical definition of density was presented, along with a discussion on fractions and how their values change. Divided into groups of four, students were provided with electronic balances, rulers, and sets of cubes made of different materials. They examined and recorded the similarities and differences between the cubes, weighed them, and ranked them in ascending order of mass. Next, they measured the edges of the cubes, calculated their volumes, and ranked them in ascending order of volume. Students then predicted which cubes would float or sink in water and recorded their guesses. They tested their predictions by placing the cubes in water and noting the results. The activity concluded with a group discussion to analyze their findings and address the cognitive conflict arising from results that contradicted their initial beliefs.

At the same time, the teacher prepares the experimental set-up 1 shown in Figure 18.

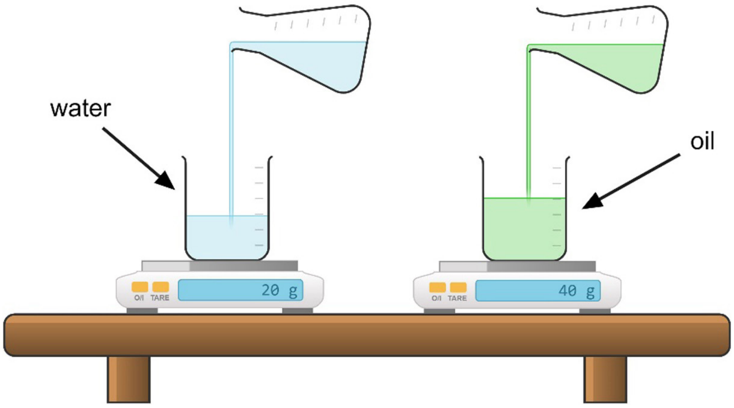

**Fig. 18.** Experimental setup 1

As shown in Figure 18, the water in the container is smaller in both mass and volume than the corresponding container containing oil.

- The teacher invites students to observe the arrangement and then guess what will happen if the two liquids mix. “I wonder if the heavy liquid, which seems to have the largest volume as well, is likely go to the bottom of the container.”
  - The conclusion to be drawn from this process is that, ultimately, for a body to float or, respectively, to sink, neither the mass of the body nor its volume matters.
- The teacher then volumetrically measures each liquid and makes the corresponding quotient $\frac{m}{V}$, for both water and oil. The values of each quotient corresponding to the density of each material are given in the table.
- Following, the teacher empties the contents of one container into the other and invites the students to interpret the result.
  - Eventually, the students realize that the liquid at the bottom of the container is not necessarily the one with the greatest mass or volume, but the one with the greatest density.

## 4.2 Activity 2

The next activity, called experimental setup 2, is shown in Figure 19.

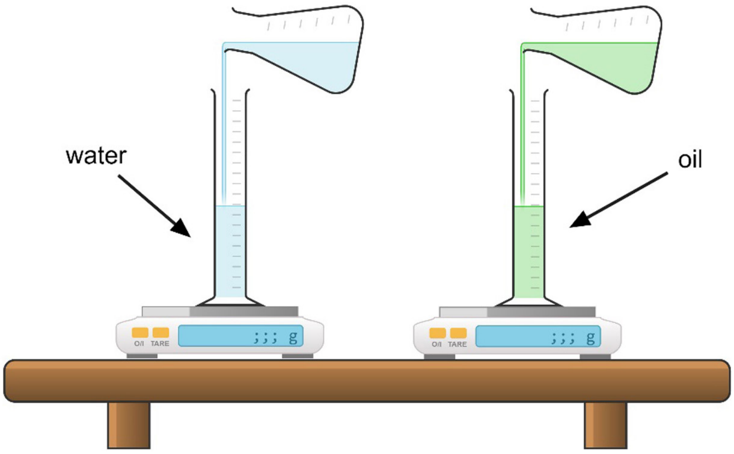

**Fig. 19.** Experimental setup 2

Two empty, identical volumetric cylinders are placed on corresponding electronic scales whose readings have been reset to zero. Students are asked to fill the volumetric cylinders with water and oil, respectively, of equal volume. They are then asked to record the readings from the two scales.

- The reading on each scale will be different. It does not mean that if the volume of the bodies is the same, their mass will be the same.
- What students are asked to find out, using the definition of density and the concept of a fraction, is that between two fractions with the same denominator (same volume), the larger fraction is the one with the larger numerator. This conclusion should be combined with the conclusions of activity 1.

## 4.3 Activity 3

The next part of the teacher's presentation involves the construction of experimental setup 3, which is shown in Figure 20.

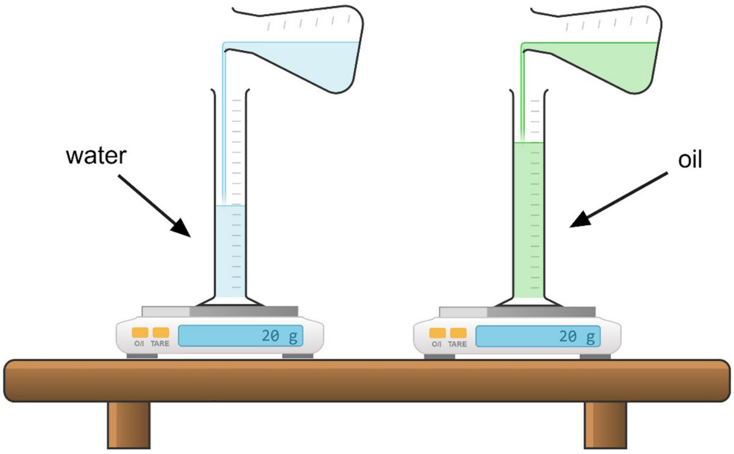

**Fig. 20.** Experimental setup 3

Two empty, identical volumetric cylinders are placed on corresponding electronic scales whose readings have been reset to zero. Students are asked to fill the two volumetric cylinders so that, this time, the two scales have the same readings. They are then asked to record the readings from the two volumetric cylinders.

- The height of each liquid in each volumetric cylinder is different, which means that the volume of the bodies is not necessarily the same since their masses are equal.
- What they are asked to find out, using the definition of density and the concept of a fraction, is that between two fractions with the same numerator (same mass), the one with the lowest denominator is larger. This conclusion should be combined with the conclusions of activity 1.

## 4.4 Activity 4

In the next activity, students are asked to fill two identical volumetric cylinders with different amounts of the same liquid, record the values of mass and volume, and finally calculate the density in each case (see Figure 21).

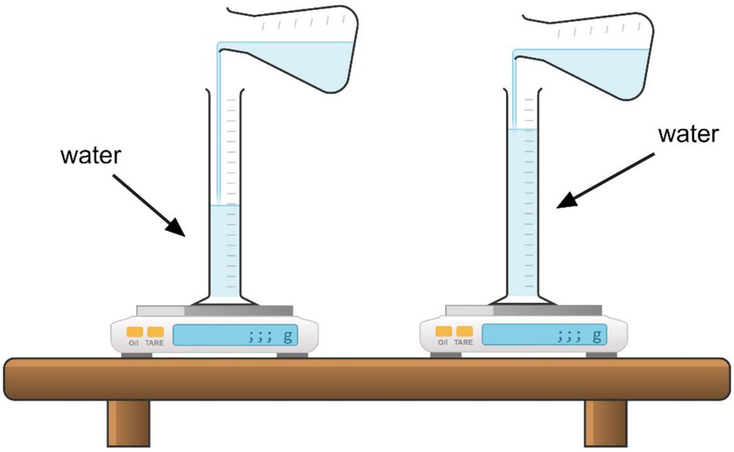

**Fig. 21.** Experimental setup 4

- In this way, the fact that density is a physical property of bodies and its value characterizes the material is highlighted. In any case, for the same material, the quotient $\frac{m}{V}$ remains constant, independent of mass and volume.
- Another conclusion is that for the same material, the mass and volume of the body are proportional.

We anticipated that teaching procedural and epistemological knowledge described above would not only boost students' understanding but also sustain it long-term. This improved knowledge would deepen students' grasp of both floating and sinking phenomena and the concept of density. We argue that floating and sinking activities would help students appreciate density as an intensive property of materials. A new understanding of density would lead students to reorganize their explanatory frameworks, thereby improving their ability to interpret floating and sinking phenomena in the future.

Once the teaching of the unit was completed in the way suggested above, the same students were asked to answer the same questionnaire in the next lesson and at the same time. The purpose of the exercise is to ascertain the change or not in their mental model after the proposed teaching.

## 5 RESULTS AND DISCUSSIONS

The 47 students answered the 15 questions in the time allotted. Figure 22 shows the percentage of correct and incorrect answers for each question before the main teaching of the module.

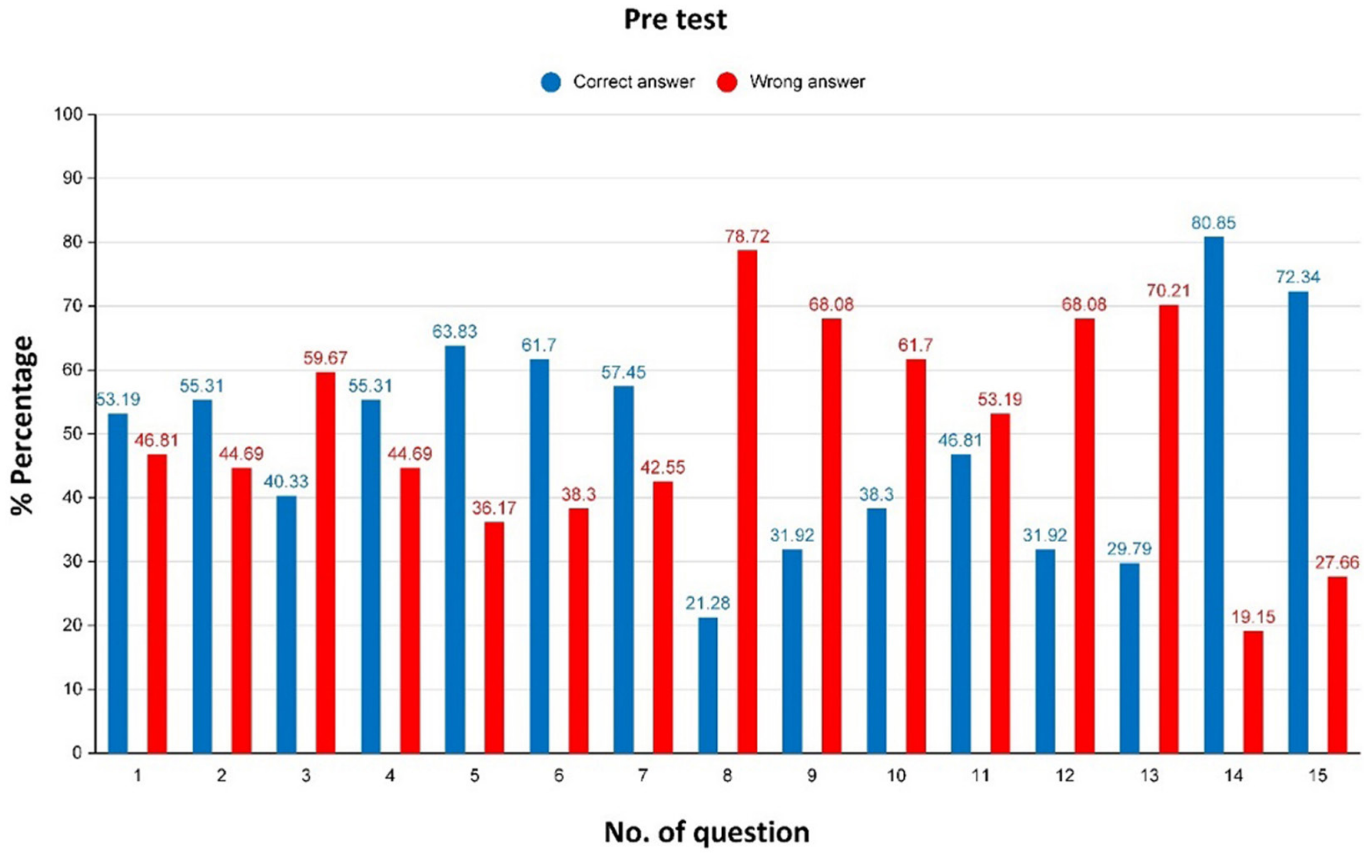

**Fig. 22.** The percentages of correct and incorrect answers before teaching

The analysis of the graph in Figure 22 reveals that students, prior to the instructional intervention as outlined in our proposal, exhibited significant misconceptions regarding the concept of floating or submerging a body in a liquid. The structured questions and response options effectively highlighted these misunderstandings.

According to the categorization of the questions, questions 1–7 in Table 1, which have mass and volume as indicators, had an average success rate of 55.30%.

In question 1, students were tasked with determining the arrangement of three different liquids of varying volumes and masses when combined in the same container. This aimed to assess their understanding of density as a crucial factor. Notably, 53.19% of the students correctly identified the order, indicating some initial understanding of density's role, though room for improvement remained.

For question 2, students had to decide which of two volumetric cylinders containing liquids of the same volume was heavier, based solely on their understanding of density. A majority of 55.31% managed to correctly distinguish between mass and volume, demonstrating a moderate grasp of the concept.

Question 3 presented a reverse scenario with two different liquids of the same mass but different volumes. Students had to predict their arrangement when combined in one container, focusing on density rather than volume to determine which liquid would sink. Only 40.33% provided the correct answer, indicating a challenge in applying the concept of density over volume.

In question 4, understanding the relationship between the densities of two cubes and water was crucial. Students needed to consider density beyond just mass, with 55.31% of the sample successfully doing so.

Question five involved two cubes of equal mass, one submerged in water. Students had to assess if the smaller volume of cube A would cause it to submerge as well. This tested their ability to compare densities without being misled by volume, with 63.83% answering correctly.

Question six aimed to simplify the concept of floating and sinking to density. Students had to determine if a larger volume cube B, made of the same material as floating cube A, would float or sink. The correct answers reached 61.7%, showing some misconceptions but also a fair understanding of density's impact.

Lastly, question seven involved two layered liquids in a volumetric cylinder. Students were asked if the arrangement would change if the volume of the first liquid exceeded that of the second. Here, 57.45% answered correctly, indicating a moderate understanding of density over volume.

Misconceptions were especially prominent in the first indicator (questions one-seven), with a notable 44.70% of students confusing the concepts of mass and volume as determining factors rather than understanding the role of density in floating. Our findings align with those of Yin et al. [2], Zoupidis et al. [9], and Vosniadou et al. [29], which also identified difficulties in distinguishing between density, mass, and volume. These results underscore the persistent challenges students face in comprehending the concept of density, as reflected in both our study and the broader literature.

Similarly, questions eight and nine, which focused on the surface area of a body, had a low average success rate of 26.60%. In question eight, students were asked to predict whether a halved submerged copper cube would float or sink, with only 21.28% answering correctly. Question nine asked if a copper sheet would float or sink under the same conditions as a submerged copper cube, with a success rate of 31.92%, indicating significant misconceptions regarding surface area and floatation.

The second indicator (questions 8-9) pertains to the surface area of a body. In questions eight and nine, there were serious misconceptions with an average rate of 73.40%, primarily related to the surface area of the submerged body. Our findings are in alignment with the international literature, which highlights similar challenges. Yin et al. [30] noted that students often confuse the impact of surface area on flotation. Smith et al. [33] observed that misconceptions about surface area are common among learners. Havu-Nuutinen [35] found that students struggle to correctly apply the concept of surface area in practical scenarios, and Fassoulopoulos et al. [28] also confirmed these difficulties, emphasizing the need for clearer instructional methods to address these misunderstandings.

Questions 10–13 focused on whether a hollow body necessarily floats, with an average success rate of 36.71%. In question 10, students determined if a solid cube A would float or sink compared to a hollow floating cube B, with only 38.3% answering correctly. This revealed a difficulty in focusing on density rather than the hollow/solid nature of the cubes. Question 11 required students to infer if a solid cube A, which is lighter than a hollow cube B, would float, with 46.81% answering correctly. Question 12 asked if a hollow cube B would float while a solid cube A was submerged, with a success rate of 31.92%, again highlighting the misconception that hollow bodies always float. Question 13 explored whether removing a part from a solid cube would change its floating status, with only 29.79% success, further illustrating this misconception.

The third indicator addresses whether a hollow or solid body necessarily floats, with an average misconception rate of 63.29%, as noted in the works of Yin et al. [2]

and Zoupidis et al. [1]. Our findings are in alignment with these studies, which also observed significant misunderstandings about the floating behavior of hollow versus solid bodies.

The final indicator, whether the amount of liquid affects floating or sinking, was addressed in questions 14 and 15. These questions had the highest success rates, averaging 76.60%. In question 14, students judged if removing water would change the floating status of a cube, with 80.85% correct answers. In question 15, students determined if adding water would affect a submerged cube's status, with 72.34% answering correctly.

Students displayed the fewest misconceptions concerning whether the amount of liquid influences an object's ability to float or sink. This contrasts with findings from Yin et al. [30] and Zoupidis et al. [1], who highlighted issues with this misconception in their study. In our case, the rate of incorrect responses was relatively low, at only 23.40%. Our findings align less with these studies, suggesting that students in our sample better understood the relationship between liquid quantity and flotation.

At the end of the proposed teaching, the students completed the questionnaire again, with the results shown in Figure 23.

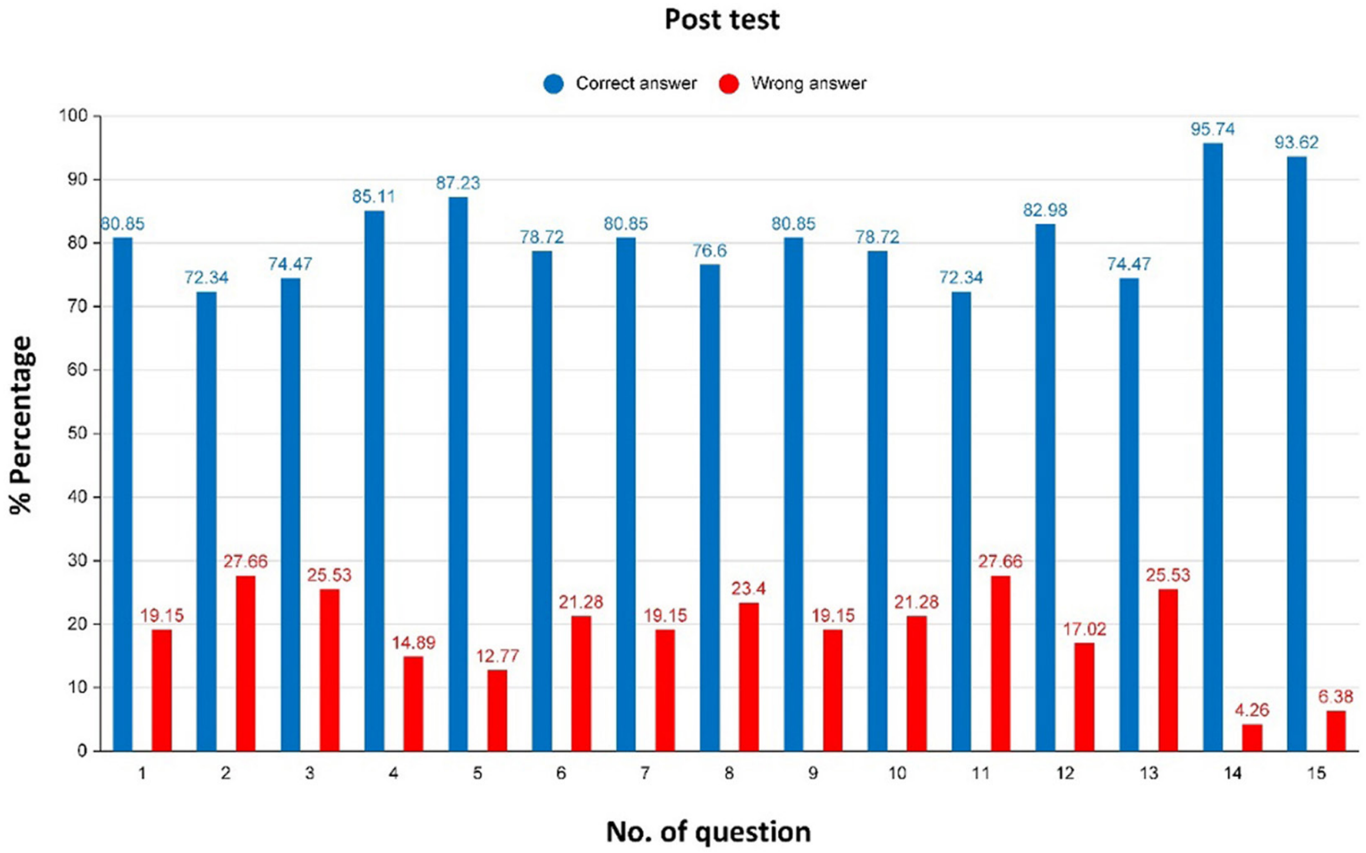

**Fig. 23.** The percentages of correct and incorrect answers after teaching

Making a simple comparison of the graphs of Figures 22 and 23, the difference in the students' correct response after the proposed instruction is evident.

Thus, the first index with mass and volume studied in questions one–seven showed a significant increase of 24.64%. Following the educational intervention, there was a corresponding enhancement in students' understanding of the concept of density and the phenomena of floating and sinking, with a notable correlation between the two as outlined in the conclusions of Smith et al. [33]. In line with the study by Wiser and Smith [42], it was observed that density, rather than weight or volume, is the key determinant in whether objects float or sink.

The index of body surface area showed the most significant increase, by 52.13%, as it was the index that initially showed the smallest proportions. Students demonstrated the most significant improvement in questions eight and nine relative to other questions, consistent with findings by Perkins and Grotzer [39] and Zoupidis et al. [8], who suggest that the most substantial improvements are often seen in areas where the deepest misconceptions are initially present, supporting the idea that starting from a lower baseline can lead to higher gains.

The third indicator, related to hollow or solid bodies, was the misconception with the second-lowest success rate. After the teaching proposal, students showed an increase of 40.42%, agreeing with Perkins' conclusions regarding poor performance and the prospects for improvement [39].

Finally, the indicator on the quantity of water also improved its percentages by 18.08%, eliminating any suspicion of misconception that existed prior to the teaching proposal, which in any case ranged at very low percentages.

Overall, the scores of the correct answers to the questionnaire before and after the teaching are shown in Figure 24. A general comment that can be made by looking at the preceding research is the emergence of the importance of the experiment as central to the teaching of physics, a fact that Itakura, McDermott, White, and Gunstone [50, 51, 52, 53, 54, 55, 57] also point out in their papers. At the same time, it is evident from the students' results in the questionnaire after the teaching proposal that with proper teaching, all misconceptions are addressed, leading to deeper understanding, as stated by Perkins and Grotzer [39]. A gradual building of knowledge can lead to an explanation of a range of phenomena [63].

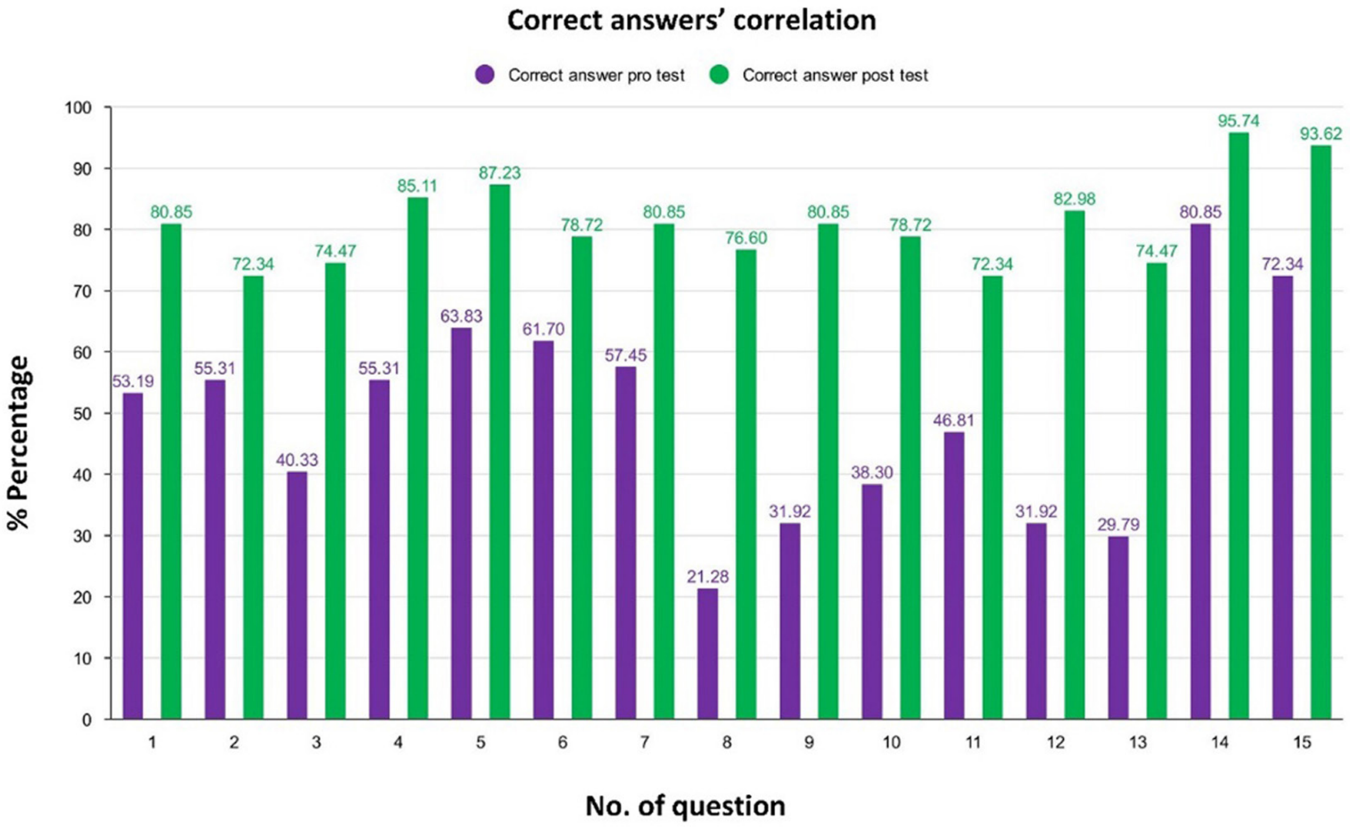

**Fig. 24.** Correlation of students' correct answers before and after teaching

## 6 CONCLUSIONS

In this study, an attempt was made to highlight the misconceptions of Greek junior high school students on the issue of floating and sinking bodies. For this purpose, a questionnaire consisting of 15 questions was constructed after a study of the relevant literature and discussions with teachers in Greek junior high schools. The questions were in the form of multiple-choice, and the answer choices were carefully structured so that the study was based on four main indicators: the mass and volume, the surface area of the bodies, whether they were hollow or solid, and the amount of liquid contained in the container in which the body was to be immersed. Through the students’ responses preceding the teaching, these specific misconceptions were identified. Then, a specific teaching proposal for approaching the issue was submitted, and the strategies for teaching the unit were analyzed. The described activities included four distinct tasks focused on measuring density. Through these experiments, the concept of density was connected to the phenomena of floating and sinking. These activities were thoughtfully crafted to encourage students to reconsider and correct any misconceptions they may have had, facilitating conceptual change. Students were then able to relate floating and sinking phenomena to the concept of density, which was the aim of this study.

At the conclusion of the teaching session, the same questionnaire was administered again, and the results affirmed the effectiveness of the proposed approach. There was a notable improvement in student performance across all questions, clearly indicating that this method successfully addressed and corrected their initial misconceptions, with improvement rates ranging from 18.08% to 52.13% depending on the indicator-misconception we aimed to measure.

Another point to be emphasized is that the proposed way of teaching and the scenario of approaching the issue avoided the time-consuming procedures of other studies, saving valuable time in the context of the course. [34]. This approach is particularly useful as the phenomenon of floating and sinking is a simple application of density in the physics course. The syllabus for each class includes many concepts, while the semester time is limited.

Our study supports the hypothesis that instructing students in procedural and epistemological knowledge significantly enhances and sustains their understanding over time. This enriched knowledge notably deepens their comprehension of floating and sinking phenomena as well as their grasp of the concept of density. Our findings further suggest that engaging students in floating and sinking activities effectively aids in recognizing density as an intensive property of materials. Ultimately, acquiring a nuanced understanding of density enables students to reorganize their explanatory frameworks, substantially improving their capacity to analyze and interpret floating and sinking phenomena in future contexts. This study underscores the enduring impact of targeted educational strategies on student conceptual development.

The relatively small sample of 47 junior high school students could be said not to allow generalizations in our conclusions, although the misconceptions identified are in full alignment with the international literature. To generalize the findings, future research could involve a larger sample of students from multiple junior high schools in Athens while maintaining the same teaching approach and questionnaire.

Even if the number of students remains the same in future research, each school year is different, making the results vary from one to another. One potential study could involve comparing the results annually to assess how this specific teaching proposal performs over time. The long-term retention of the scientific knowledge gained by the students in the sample could be assessed by redistributing the same questionnaire to the same group of students in subsequent junior high school grades.

Future teaching strategies can incorporate the proposed teaching method that approaches floating and sinking phenomena, which has been shown to bring about significant improvement and understanding of the subject matter as our results revealed and future research will highlight its validity over time.

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