JPPIPA 12(1) (2026)

Jurnal Penelitian Pendidikan IPA

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Designing a Test Instrument to Reveal Students' Reasoning Abilities on Archimedes' Principle

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Received: November 12, 2025
Revised: December 22, 2025
Accepted: February 07, 2026
Published: February 07, 2026

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DOI: 10.29303/jppipa.v12i1.13440

Abstract: Visuo-haptic simulator-based learning can help students understand the relationship between buoyancy and the volume of displaced fluid. In this study, students experienced a physical simulation of an upward force, which has been shown to improve conceptual understanding and reduce misconceptions commonly found in traditional classrooms. This study aimed to design a test instrument that could reveal in detail students' reasoning abilities related to Archimedes' Law, specifically regarding the phenomena of floating, levitating, and sinking. The study used a qualitative approach through two stages of testing administered to 31 first-year physics students who had taken a basic physics course. The initial test used the five-block problem developed by Loverude to identify students' reasoning patterns, which mostly showed misconceptions, such as determining the final position of an object based on mass rather than density. Based on this analysis, four diagnostic questions were developed to explore students' understanding of the differences between density, buoyancy, and the application of Newton's Laws in the context of fluids. The test results showed that although students had some correct knowledge, they often failed to apply it correctly, especially in cases involving more than one object or in calculating the volume of displaced fluid. Based on these findings, the instrument was developed into six tested and validated items capable of comprehensively assessing students' reasoning abilities and conceptual understanding. This instrument can be used by educators to diagnose and correct student misconceptions related to Archimedes' Law.

Keywords: Archimedes' law; Floating-sinking concept; Instrument development; Reasoning ability

Introduction

This research is based on several previous studies that revealed students' difficulties in solving problems related to the application of Archimedes' Law in everyday life. The research results show that many high school students, and even university students, still experience errors in analyzing phenomena related to these events. Since half a century ago, physics education researchers have become increasingly aware that many students experience difficulties in understanding fundamental concepts in physics. Difficulty understanding concepts does not mean that students do not have correct knowledge at all but rather is due to students' failure to activate knowledge relevant to the problem. Several research results show that many students still experience difficulties in understanding physics concepts (Diyana et al., 2020; Shishigu et al., 2017; Taqwa & Taurusi, 2021; Wambugu & Changeiywo, 2008). One of them is the concept of static fluids in relation to the reasoning ability on Archimedes' Law material (Taqwa et al., 2024; Zulfa et al., 2020). Recent research reinforces the fact that misconceptions in this material are universal and occur across educational levels (Amin et al., 2015; Kaltakci Gurel et al., 2015). Schwichow & Zoupidis (2024) in a meta-analysis of 69 studies of "floating and sinking" learning found that conceptual difficulties occur because students fail to integrate the concepts of density, buoyancy, and fluid pressure simultaneously.

How to Cite:
Sukariasih, L. (2026). Designing a Test Instrument to Reveal Students' Reasoning Abilities on Archimedes' Principle. *Jurnal Penelitian Pendidikan IPA*, *12*(1), 648-656. https://doi.org/10.29303/jppipa.v12i1.13440

Similar results were also found by Castillo-Hernández et al. (2025) who stated that more than 70% of prospective physics teachers still understand buoyancy as a direct result of the weight of an object, not the volume of fluid displaced. These findings align with research by Neri et al. (2024); Saputra & Mustika (2022), which showed that conceptual errors related to the relationship between density and buoyancy persisted even after experimental interventions. Static fluid is a fluid that is at rest or not experiencing flow. The study of static fluids in physics encompasses the principles governing the pressure and forces acting on fluids and the objects within them. Static fluids cover hydrostatic pressure, Pascal's law, and Archimedes' law (Alatas, 2019). Archimedes' law is a law that explains the concept of floating objects in fluids. Archimedes' law states that an object floats in a fluid if the density of the object is lower than the density of the fluid in which it is located (Naylor & Tsai, 2022).

Students' difficulties in understanding Archimedes' principle are often caused by a failure to connect the buoyant force with the volume of fluid displaced. A knowledge integration approach has been shown to improve students' scientific reasoning abilities regarding the relationship between density and volume of liquids. Similarly, Kriek & Legesse (2023) confirmed that a multiple representation instruction strategy using graphs, images, and simulations significantly improves conceptual understanding of buoyancy and fluid pressure. Some difficulties in students' reasoning about floating and sinking have been revealed in the physics education research literature. Several studies reveal that students have misconceptions about floating and sinking, such as misunderstanding the relationship between density, object weight, and buoyancy, and the inability to analyze the relationship between floating events and fluid pressure (Paik et al., 2017). A very common error is that many students assume that the position of an object affects the magnitude of the upward force (buoyancy) even though the object is completely submerged.

The buoyancy force will be zero if the object sinks to the bottom of the container. Students assume that objects sink in water because the object is heavier than water. Other findings reveal that students also assume that the sinking or floating state of an object is determined by the mass or weight of the object (many students still assume that the mass of an object is the same as the weight of the object), without paying attention to its volume. In this context, students generally think that the lower the position of an object in the fluid, the smaller the buoyant force it experiences and that it has a value of zero if the object sinks to the bottom of the container. Confirmation of these errors has been formulated based on the results of research conducted using the five blocks problem developed.

Visuo-haptic simulator-based learning can help students understand the relationship between the buoyancy force and the volume of displaced fluid. In this study, students experienced a physical simulation of an upward force, which has been shown to improve conceptual understanding and reduce misconceptions commonly found in traditional classrooms. In general, student errors are caused by their inability to activate the appropriate concepts in the appropriate context (Turşucu et al., 2020). This relates to students' ability to use appropriate reasoning to solve problems (Richards et al., 2020). This study aimed to develop a test instrument that could reveal in more detail the existing pieces of physics knowledge students already possess and how they use this knowledge coherently and coordinately to solve the five-block problem. The questions were designed based on findings generated through tests using the five-block problem.

Research by Solé-Llussà et al. (2022), demonstrated that the use of graded diagnostic tests and video worked examples is effective in assessing students' thinking processes and analyzing their reasoning. Furthermore, Weißenfels et al. (2023) highlighted the concept of academic buoyancy, which emphasizes students' learning resilience in the face of conceptual difficulties; this approach can enrich the design of instruments to measure the dynamics of students' scientific reasoning. Thus, this research design not only aims to detect misconceptions but also provides an empirical basis for the development of hands-on learning interventions and visuo-haptic integration.

Method

This study was conducted with the aim of developing a test instrument that can be used to reveal in more detail the reasoning used by students in solving the phenomenon of Archimedes' Law (floating, hovering, and sinking). The method used in this study was a qualitative research method through the administration of a test. The test consisted of two parts. First, the researcher administered a test on the five-block problem previously developed. The test was given to 31 first-year physics students at a State University in Southeast Sulawesi. Subjects were selected using purposive sampling considering that they had taken basic physics courses that included static fluid material. Next, based on the students' answers to the five-block problem, the researcher developed an instrument consisting of 4 (four) questions to more deeply track the students' understanding and reasoning regarding the elements of knowledge relevant to analyzing the floating, hovering, and sinking phenomena. Next, the test was re-tested on the same students to reveal the students' understanding more comprehensively. Finally, the questions were reconstructed by referring to the findings of tests 1 and 2 so that 6 (six) questions were produced which were considered capable of revealing the students' reasoning and understanding related to the floating, hovering, and sinking events (Archimedes' Law Concept). The questions that were compiled had been validated by experts in the field through FGD (focus group discussion) activities which were carried out in several sessions until producing an instrument that could truly measure students' reasoning abilities on the concept of Archimedes' Law.

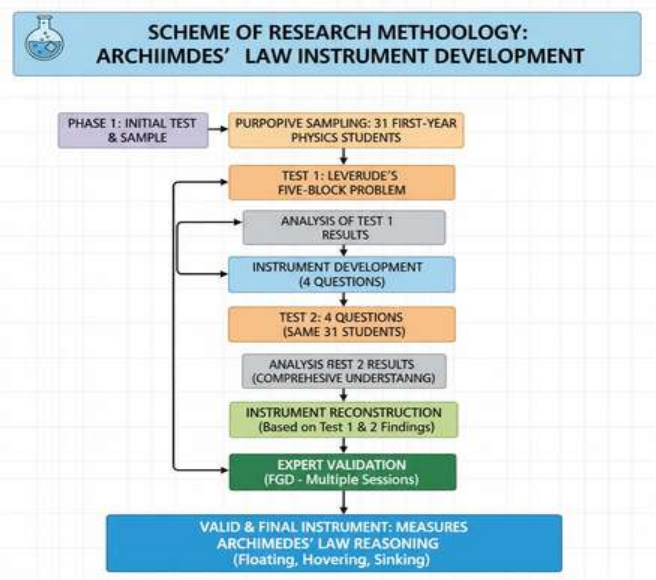


Figure 1. Schematic diagram of the research method

Result and Discussion

The findings of this study will be described in two stages. The first stage contains data from test results using the five-block problem developed by Pedaste et al. (2015); Schantong et al. (2025). The second stage presents the rationale for developing a test instrument designed to uncover the reasoning used by students when solving problems related to Archimedes' Principle.

Description of Students' Ability to Solve the Five-block Problem

The following data demonstrates students' ability to solve the five-block problem developed by Araujo et al. (2013); Barraood et al. (2022); Han et al. (2019). Five blocks are the same size but have different masses. The blocks are numbered according to their mass. All blocks are released into the water (aquarium), approximately halfway down the aquarium. If the final positions of blocks 2 and 5 are shown as in the figure, describe the final positions of blocks 1, 3, and 4 and provide a rationale. (Assume that water is incompressible and homogeneous, so that its density is the same everywhere.)

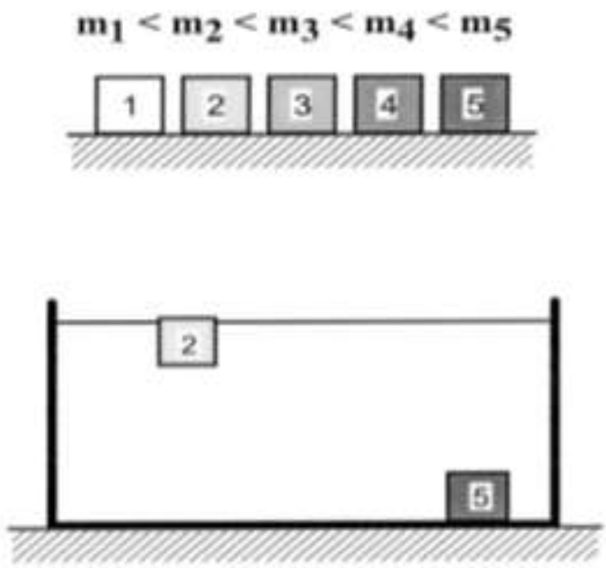


Figure 2. Picture of the five blocks problem

Based on the written answers from students to the five blocks problem, it was found that no student was able to solve the problem correctly. Almost all student answers were as shown in Figure 1, namely the five blocks formed a downward sloping line formation with block 1 at the top and block 5 at the bottom. The correct answer to this problem has two possibilities as shown in Figure 3. The following is the explanation. Because m2 < m3 and m2 almost floats, meaning the density of block 2 is greater than the density of the fluid, the density of block 3 will be one of two possibilities, namely the same as the density of the fluid or greater than the density of the fluid: The first possibility is as shown in Figure 3(a), if it is assumed that the density of block 3 is the same as the density of the fluid, then the resultant force acting on block 3 will be equal to zero so that the position of block 3 will be exactly in the middle of the aquarium (the position where the block is released). Because the mass of block 4 is greater than the mass of block 3, block 4 sinks and block 1 floats above block 2; The second possibility is as shown in Figure 3(b), if it is assumed that the density of block 3 is greater than the density of the fluid, then block 3 will experience downward acceleration and sink because the buoyant force experienced by the block is smaller than its weight. Block 4 sinks and block 1 floats above block 2.

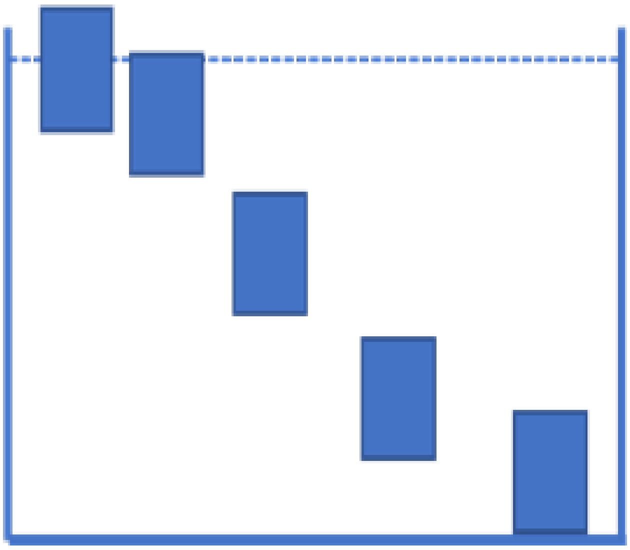
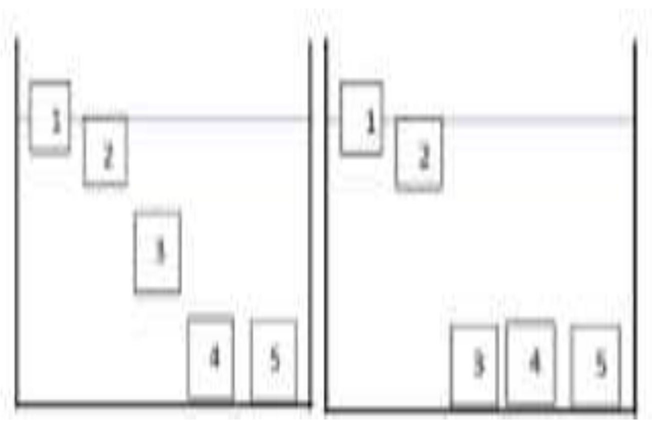


Figure 3. Student answer format for the five block question



(a) (b)

Figure 4. Possible correct answers to the five-block problem

Table 1. Student reasoning on the five-block program

Specific Reasoning	Percentage (%)
The final position of an object depends on its density: the greater the density, the lower its position.	64.52
The final position of an object depends on its mass: the greater the mass, the lower its position.	19.35
The final position of an object is determined by the pressure it exerts, where the pressure is proportional to its mass: the greater the mass, the greater the pressure, and therefore its position is lower.	9.68
The final position of an object is determined by the difference between its weight and the buoyant force it experiences: the heavier an object, the smaller the buoyant force it experiences compared to its weight, and therefore its position is lower.	6.45

Based on the results of the constant comparative analysis of various student reasoning, four specific categories of reasoning were obtained, as presented in Table 1. These four categories can be further summarized into two categories as follows. The first category, the final position of an object is determined by its density (category 1 in Table 1), that is, the greater the density, the lower its final position. The second category, the final position of an object is determined by its mass (categories 2a, b, and c in Table 1), that is, the greater the mass, the lower its position. Regarding the second category, there are two more specific reasoning patterns related to the influence of an object's mass. Each of these is related to the magnitude of the pressure exerted by the object (2b) and the buoyant force of the fluid (2c).

The findings in Table 1 align with previous research findings that students tend to think about whether an object sinks or floats based solely on its weight or volume, based on their everyday experiences. For example, large or heavy objects sink, while small or light objects float (Irma et al., 2022; Radovanović et al., 2019; Wagner et al., 2014). These findings also align with other research showing that students' thinking about buoyancy is often based on only one dominant feature of the phenomenon, in this case, the object's mass (Maison et al., 2023; Zoupidis et al., 2021). From a cognitive perspective, it is emphasized that difficult-to-change misconceptions arise from low inhibitory control—the ability to suppress initial, erroneous intuitions. Therefore, learning that emphasizes cognitive conflict and direct experimentation is recommended to help students improve their reasoning structures (Almulla, 2023; De Jong et al., 2023).

Developing a Test Instrument to Measure Reasoning Ability

In the next stage, the researcher developed a test instrument to reveal the reasoning used by students when solving problems related to Archimedes' Principle. The instrument construction, leading to the final instrument, was carried out in two iterations. The first instrument was developed based on findings obtained when students solved the five-block problem (as presented in Table 1). Next, the researcher constructed four questions to reveal students' reasoning abilities related to the application of Archimedes' Principle (Fernando et al., 2024; Hardy et al., 2022; Nooritasari et al., 2020). Questions 1 and 2 were identical, exploring students' reasoning related to density by modifying the position of the block when it was released. Questions 3 and 4 sought to reveal students' reasoning about the buoyant force experienced by the block in the fluid, which students had to relate to Newton's Law. The following is a description of the test instrument. A block is placed in an aquarium filled with water, as shown in the image to the right. The dotted line indicates the midpoint of the water in the aquarium. The block is initially held in the position shown in the image, then released.

Figure 5. Block floating above the centerline

If the density of the block is slightly greater than the density of water, will the block move after being released? If so, where will it move? Sketch the final position of the block after it returns to rest; If the density of the block is exactly the same as the density of water, will the block move after being released? If so, where will it move? Sketch the final position of the block after it returns to rest; If the density of the block is slightly less than the density of water, will the block move after being released? If so, where will it move? Sketch the final position of the block after it returns to rest.

A block is placed in an aquarium filled with water, as shown in the figure. The dotted line indicates the midpoint of the water in the aquarium. The block is initially held in the position shown in the figure, then released.

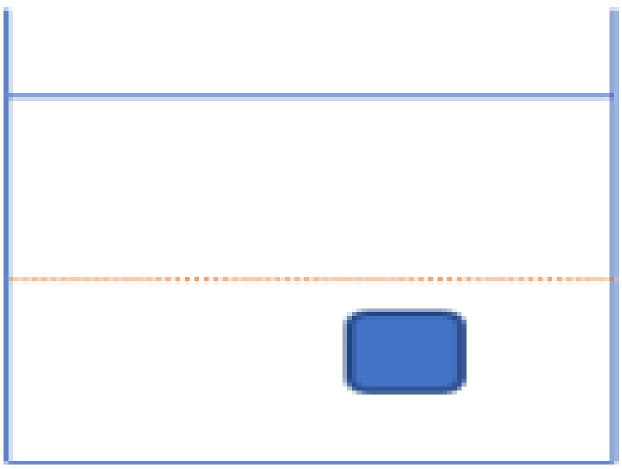


Figure 6. The block floats below the center line.

If the density of the block is slightly greater than the density of water, will the block move after being released? If so, where will it move? Draw the final position of the block after it returns to rest. If the density of the block is exactly the same as the density of water, will the block move after being released? If so, where will it move? Draw the final position of the block after it returns to rest.; If the density of the block is slightly smaller than the density of water, will the block move after being released? If so, where will it move? Draw the final position of the block after it returns to rest. Three identical blocks are placed in water at different positions as shown in the following figure. All three blocks are at rest and the dotted line indicates the midpoint of the water.

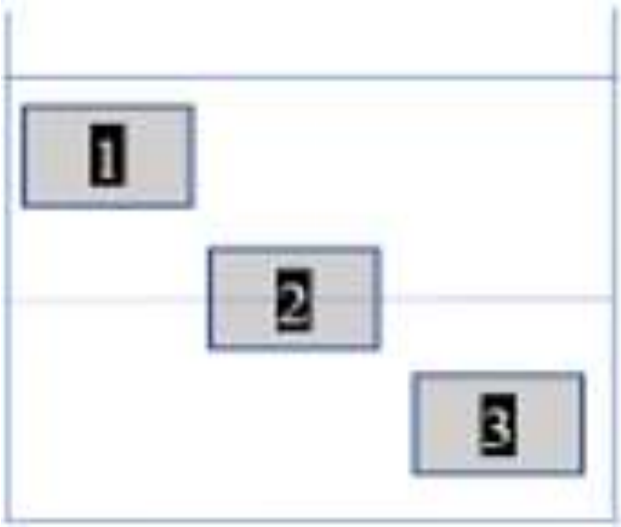


Figure 6. Three identical blocks floating in a fluid

Note:

Which block floats?; How do the densities of the three blocks compare? If they are different, rank them from the one with the largest to the smallest density; What forces act on each block?; Is it only the buoyant force or the gravity force or both? Describe the forces acting on each block!; Determine the resultant force acting on each block.

block! the picture below. A measuring cup is initially filled with 500 cm3 of water (5.0 x 10-4 m3). Then, a block is placed in the liquid and the block is in a floating state. The water level in the measuring cup rises to a scale of 550 cm3 (5.5 x 10-4 m3). The density of water and the acceleration due to gravity at the experimental location are g = 10 m/s2 and ρwater = 1000 kg/m3, respectively.

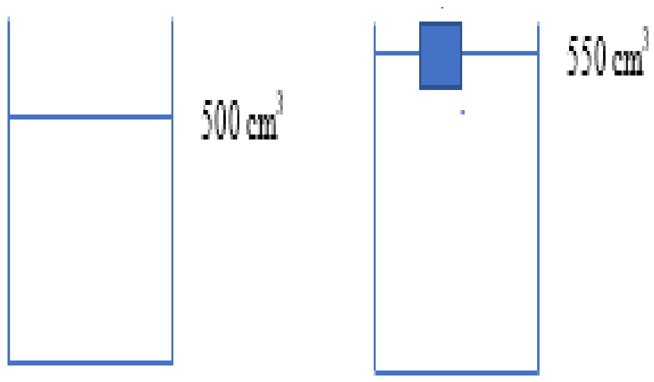


Figure 7. Volume of liquid before and after the block is inserted

The following is a description of student understanding after being given the problems in the four questions above. Students have sufficient knowledge about the phenomena of floating, hovering, and sinking due to the difference in density of an object with respect to the density of a fluid; blocks float because they have the same density as water and are always located in the middle of the liquid; students appear to have sufficient knowledge but often fail to apply this knowledge due to being triggered by prominent features that appear in the context of the problem (Getie, 2020; Lodge et al., 2018; Schneider & Simonsmeier, 2025). It is suspected that students are confused about applying their knowledge to problems involving more than one block in a container; they are still incorrect in determining the volume of liquid displaced if the liquid does not spill from the container; students still have not used the concept of forces acting on blocks in liquids and the interactions that occur, related to the application of Newton's laws. Based on these findings, the researcher then reconstructed the instrument with the following description. Question 1 is a five-block problem developed by (Carbajal & Baranauskas, 2025; Schantong et al., 2025). Questions 2, 4, and 5 are taken from four questions compiled based on the first findings (the complete questions and rubric can be found in the appendix). Question 3 was designed to reveal students' reasoning regarding the forces acting on blocks in a liquid and their interactions using two identical blocks suspended in different positions. Question 6 was designed to reveal students' reasoning about forces and resultant forces on objects moving and at rest in a liquid.

The following describes two additional questions constructed based on the findings from the second test. Two blocks of the same size and mass are placed in a container as shown in the following figure. The dotted line indicates the midpoint of the water in the container. Each block is held in a floating position as shown in the figure and then released. Describe the final position of each block after release if:

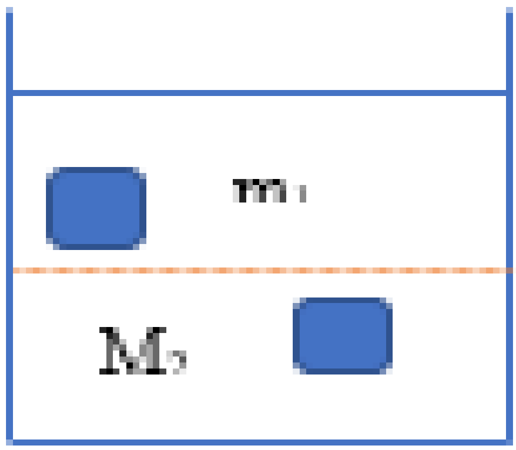


Figure 8. Description of 2 additional questions

Note:
$P_{object} > \rho_{water}$
$P_{object} = \rho_{water}$
$P_{object} < \rho water$

A block with a density of 0.99 gr/cm3 is immersed in a liquid with a density of 1.00 gr/cm3. If the block is initially held in the position shown in the following image,

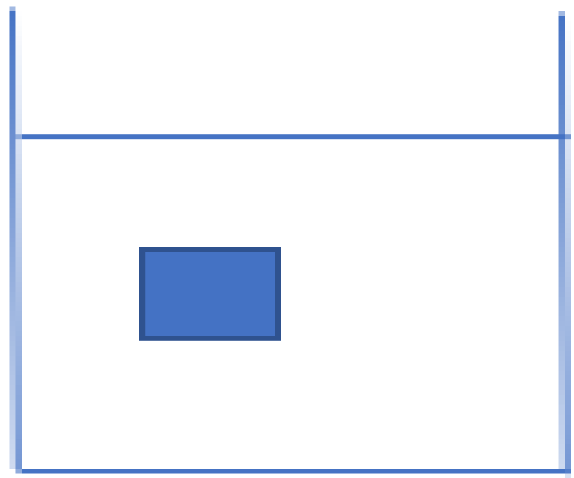


Figure 9. Description of 2 additional questions

Describe the final position of the block after it is released; Where does the block move after it is released? Why?; What about the buoyant force experienced by the object right after it is released? Is it greater than or equal to W?; When the object is at rest, in its final position, what is the buoyant force experienced by the object?

Conclusion

This study successfully designed and validated a test instrument capable of revealing in detail students' reasoning abilities on the material of Archimedes' Law, specifically regarding the phenomena of floating, levitating, and sinking. The findings showed that students generally have the correct basic knowledge but often fail to apply it appropriately because they are fixated on dominant features such as the mass of objects, and experience misconceptions related to buoyancy, density, and the application of Newton's laws in the context of fluids. The final instrument consisting of six questions proved effective in diagnosing misconceptions and assessing comprehensive conceptual understanding. This instrument is expected to be used by educators as an evaluation tool as well as a learning-improvement tool so that students' understanding of Archimedes' Law becomes more precise and integrated.

Acknowledgments
Thanks to all parties who have supported the implementation of this research. I hope this research can be useful.

Author Contributions
Conceptualization; methodology.; validation; formal analysis; investigation; resources; data curation; writing—original draft preparation; writing—review and editing.; visualization: L. S. All authors have read and agreed to the published version of the manuscript.

Funding
The research and writing of this article were funded by personal funds.

Conflicts of Interest
The researchers funded this research independently.

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