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Students' Mental Models about the Suspending Objects in Static Fluid

Jusman Mansyur[1], I Komang Werdhiana[2], Darsikin Darsikin[3], Sarintan N. Kaharu[4], Nurgan Tadeko[5]

[1]*Tadulako University, Indonesia, ORCID ID: 0000-0001-6126-5692*
[2]*Tadulako University, Indonesia, ORCID ID: 0000-0002-6623-557X*
[3]*Tadulako University Indonesia, ORCID ID: 0000-0003-1384-1776*
[4]*Tadulako University, Indonesia, ORCID ID: 0000-0002-2069-0921*
[5]*Tadulako University, Indonesia, ORCID ID: 0000-0003-3805-9078*

ABSTRACT
This study aims to explore the mental models of students about suspending objects in liquid fluid. The study used a descriptive qualitative method and implemented cross-sectional approach. It involved 57 students from grade 5 of elementary school to fourth-year prospective physics teachers. The data collection used a test consisting of twenty-six essay and four multiple-choice items, which covered several contexts and factors. The data were analyzed by adapted phenomenographic procedures and integrated with some stages of thematic analysis. The types of mental models that were successfully explored include the density-, mass-, weight-, volume-, and gravity-based model, leaked boat model, air as a floater model, etc. The predominant students' mental model was the initial one, followed by the synthetic and scientific level, respectively, and the adopted mental models tended to form a hierarchy based on the grade of students. The results showed that the suspending models tended to be adopted and was influenced by the mental model in the floating and sinking contexts. This result confirms the findings of previous studies, which stated that mental models depend on the context of the phenomenon being presented. The existence of variations in the students' mental models for reasoning about density and depiction of suspending objects revealed gaps in the consolidation of their mental models. In learning activities, it is not enough to teach the concepts of floating and sinking. Hence, an adequate portion for the suspending concept must be provided by depicting various object positions and emphasizing a more conceptual of density-based model..

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Introduction

Cognitive science studies of mental models have been an interesting area of research in psychology and science education (Corpuz & Rebello, 2011). This field has attracted the interest of researchers to explore learners' mental models for physical systems, which include numerous objects, events, or phenomena on a macroscopic and microscopic scale. The physical systems, which may be concrete or abstract, enable the learners to have direct and indirect experiences that form the basis of their mental models in this domain.

There are several studies on mental models concerning the macroscopic or microscopic phenomena, such as those conducted by Kaniawati et al. (2019), Nongkhunsarn et al. (2019), Ozcan & Gercek (2015), as well as Yildirir & Demirkol (2014). Other researchers include Adbo & Taber (2009), Bonnefon (2004), Borges (1999), Corpuz & Rebello (2011), and Vosniadou & Brewer (1992). Such previous studies, which involve these phenomena vary widely relating to aspects of the research, including conceptions, misconceptions, reasoning, and mental models. The study of specific contexts, such as the phenomena of floating and sinking, also has an appeal for researchers.

Floating and sinking are widely studied phenomena, taught to pre-school children and university students. These studies include research which examined the conceptual changes that occur in children aged six years (Havu-Nuutinen, 2005), eight grade students (Çepni et al., 2010) related to floating and sinking, and eleventh grade students about buoyancy (Djudin, 2021). Also, Yin et al. (2008), as well as Chien et al. (2009) , as well as Teo et al. (2017) investigated the concept of why an object floats or sinks. In addition, Howe et al. (1990) examined elementary school students' understanding of floating and sinking in peer interaction settings. Minogue et al. (2015) examined the ideas of prospective elementary school teachers about buoyancy associated with the haptic feedback system. Study by Gette et al. (2018) also explored the effects of question and instructional design, focusing on density-based arguments for floating, sinking, and neutral buoyancy cases. The study by Castillo et al. (2017) revealed that adults experience systematic errors in understanding sinking objects. Additionally, Nongkhunsarn et al. (2019) examined mental and analytical thinking models of grade 11 students regarding density and pressure in fluids through the Science Technology and Society (STS) approach.

Apart from studies on conceptions, misconceptions, and instructional design related to floating and sinking phenomena, several studies also focused on related assessments. An example is Viyanti et al. (2017), which developed rubrics as an alternative assessment for these concepts. Also, Kafiyani et al. (2019) examined a four-tier diagnostic test to identify mental models in static fluids, while Shen et al. (2017) developed an assessment and instructional design using "Released blocks" and "Cartesian diver."

Study by Gette et al. (2018) showed that students can associate floating and sinking behavior with the relative density of the blocks to water. A complete understanding of the structure that causes objects to float and sink requires non-trivial knowledge, including an analysis of the relationship between buoyancy and force (Radovanović & Sliško 2013).

Based on the description above, the focus of previous studies can be stated to be solely on the floating and sinking phenomena, which was dominant on the conception, misconception, or reasoning. Consequently, the contextual study of suspending objects did not seem to concern the researchers, and aspects of mental models of these phenomena tended to be neglected.

Apart from the absence of a study on mental models of suspending objects, this study is also based on the results of observation in school physics course with a consistent pattern. Here, the students described the suspending objects' positions, particularly in the middle of the depth of water in a vessel. When an external representation of an image containing three objects positioned varying with the depth of the water is provided, a stable object near the water surface is floating. Meanwhile, the object near the base of the vessel is said to be sinking. It can be assumed that this concept is influenced by habits in instructional activities and presentations in textbooks where the suspending object is represented as always in the middle of the depth of the liquid. Another allegation is that educators have focused only on floating and sinking objects so far. Meanwhile, suspending objects are taught to be limited to reviewing the similarity between the density of objects and liquids without adequate explanation, causing students to make simplifications. They develop personal mental models, which has implications for the depiction and representation of suspending objects. Another possibility was stated by Çepni et al. (2017) that in linking science to daily life, prospective teachers do not emphasize feelings, observe, or understand science in everyday events or situations. They witness objects at various water levels without a solid understanding of how real entities, such as submarines and fishes, maintain their suspending condition. Students did not expect that ordinary object, for example, block, to reach a suspending state is a very rare phenomenon (Gette et al., 2018).

Studies on understandings, conceptions, misconceptions, and mental models of everyday phenomena have been carried out by several researchers with a cross-sectional study approach. For example, Çepni & Keleş (2006) explored students' conceptions of simple electrical circuits and found that there were misconceptions across ages and there were certain mental models that were dominantly adopted by certain age levels. Türk et al. (2015) examined the mental models of grade 5 to grade 8 students regarding climate formation and how this model changes in terms of grade levels. The study revealed that students have various alternative conceptions and mental models that are not in line with scientific explanations. Studies in the other fields of science that applied cross-sectional approach include Coll & Treagust (2003), Gönen & Kocakaya (2010), Kurnaz & Eksi (2015), Lin (2017), Sahin et al. (2008), Vosniadou & Brewer (1992), and Vosniadou & Ioannides (1998).

From the literature review, it can be concluded that cross-sectional studies are quite widely applied to science education. However, there is no cross-sectional study that explores students' mental models for the phenomena of suspending objects in liquid fluid.

Mental Model and Representation

The study of misconceptions has led to the use of the term "mental models or representations" (Ravanis, 2019) in science education research. This term refers to internal representations that act as analogous structures of a process or situation (Greca & Moreira, 2000). Mental models are internal representations of objects, states, sequence of events or processes, the way of percieveing the world, as well as psychological, and social actions. These models allow individuals to make predictions and conclusions, understand phenomena and events, make decisions, and control their implementation (Borges, 1999).

Scientists and researchers have found various models to represent objects, events, or phenomena. These findings have raised questions about how the models affect the development of mental representations and the use of strategies as well as concept building processes by learners in the classroom. According to Mayer's theory (Canlas, 2019), an important aspect of the educational process is a visual representation, which includes the externalization of information as a visual model. It indicates that images and words, produced orally and literally, and used at the same time, can improve cognition and mental model construction. Based on this framework, it can be stated that visual representations, such as the produced images and texts, allow access to a person's mental model.

When dealing with new experiences, learners often test the adequacy of their mental models. These tests may involve many representations, rules, and procedures at any point in the development that may be challenging to implement. During the teaching-learning process, students construct and modify these mental models. Consequently, this change can be a long and difficult process, depending on the model's complexity (Corpuz & Rebello, 2011).

The ability of learners to change their conceptual knowledge is believed to depend on the flexibility of their internal representations. The theory of representational redescription (RR) by Karmiloff-Smith (1990) described the acquisition of knowledge through sequential phases. These phases started with knowledge representation in a procedural, implicit way, followed by a re-representation at various abstraction levels. According to this theory, the flexibility depends on the level of representation (van Schijndel et al., 2018).

Based on the previous studies and preliminary findings above, it is necessary to conduct a systematic study of learners' mental models and aspects related to suspending objects. Two questions have been focused during the study.

1. How were the mental models adhered by cross-grade students related to suspending objects in liquid fluid for different contexts?
2. How were the categories of mental model related to the cross-grade students?

Method

This study used a descriptive qualitative method. The study adapted a cross-sectional study. Cross-sectional studies apply indirect measurements of the nature and rate of change in physical and intellectual development where there is one time measurements (Cohen et al., 2007). Previous studies did not distinguish between cross-age studies on cognitive development with cross-grade studies on the effect of curriculum and environment (Lin, 2017; Mansyur et al., 2022). In this study, the students were selected based on grade, it was categorized as a cross-grade study. Therefore, the mental model obtained was considered as an influence of the curriculum and the environment.

Participants

This study involved students in grades 5, 6, 8, 9, 11, and 12 from public elementary schools, public and private junior, and senior high schools, along with physics student teachers in their first, second, third, and fourth years. The involved schools are among the favorite schools in Palu City, and the description of students is presented in Table 1.

Table 1

Description of participants

Grade	Code	Number of students
Primary school-Grade 5	P5	3
Primary school-Grade 6	P6	3
Junior Secondary School-Grade 8	J8	8
Junior Secondary School-Grade 9	J9	8
Senior High School-Grade 11	S11	10
Senior High School-Grade 12	S12	9
Undergraduate-Year I	U1	4
Undergraduate-Year II	U2	4
Undergraduate-Year III	U3	4
Undergraduate-Year IV	U4	4
	Total	57

The recruited students were the best in their respective classes, based on data and teacher recommendations. They were voluntarily involved and received parental consent after the school contacted them. After the students' names were obtained from the school or teacher, the research team contacted them to arrange a meeting for data collection. The involved university students were also students with the highest GPA in their group. Meanwhile, the data collection was performed at students' homes and schools as agreed, and due to the COVID-19 pandemic, the research team and students employed the necessary protocol. These protocols involved using a mask, keeping distance, and applying hand sanitizers after holding the test sheet. As part of ethical consideration, students' identities are kept confidential by using initials or pseudonyms.

Instrument

In this study, the instrument used for data collection was a test consisting of 30 items comprising an essay of twenty-six items and a multiple-choice of four (some samples of items are in Appendix A). In the essay items, the students were asked to provide brief answers, pictures, or explanations of the aspects being asked. Conversely, in the multiple-choice items, three of the asked items were to select one or more options, while the last one requested only one choice. While the dominant test items were the suspending phenomena, the floating and sinking contexts were provided to test the initial assumption that the possibility of the dominant model was influenced by mental models of both representations. The test underwent the development procedure, which showed that the items had content and face validity in the very good category. Also, it revealed that Cohen's Kappa (κ) reliability of 0.715 (sig. p = 0.000) was in the high category (Kaharu & Mansyur, 2021; Mansyur et al., 2022).

Instructions, explanations, and additional verbal information were supplied before the test, for instance, the meaning of the words "hole" and "hollow" were followed by examples and differences between the two. The basic assumption used in the test was that water as a fluid for floating, suspending, or sinking was a liquid with a density that remained unchanged or incompressible even when pressure is applied. This density is uniform or homogeneous in all parts, regardless of the depth or location of the points being studied. Another assumption concerning the material context is that objects that are cut or divided into several parts are homogeneous with a uniform density over all parts of the item. For treatments, such as the creation of a hole or hollow, the object in question is rigid.

Data Analysis

Based on the study objectives, the data were analyzed qualitatively-descriptively. The data analysis adapted phenomenographic procedures (Walsh et al., 2007) and was integrated with some stages of thematic analysis (Vaismoradi et al., 2013) as presented in Table 2.

Table 2

Data Analysis Stages

Stage		Description
I	Building familiarity with the data	Reading and re-reading the student's statements, as well as noting initial ideas.
II	Identifying emerging themes	Extracting meaning based on the students' answers or statements
III	Integrating theme and the creation of category descriptions	Grouping themes based on the types of students' answers, composing descriptions based on extracted characteristics or meanings, grouping the students into description categories
IV	Giving a name to the theme	Giving names to the mental models
V	Arranging the outcome space	Preparing tables containing the outcome space and the description categories of the mental model
VI	Categorizing and leveling	Constructing a mental model hierarchy

The naming of the mental model adapted the methods proposed by Harrison & Treagust (2000), Shen et al. (2017), and Nongkhunsarn et al. (2019). For example, a hole was made in the objects in the context of floating, suspending, or sinking, then the students' mental model was to give names, such as the density-based model, mass-based model, etc. If respondents relate the effect of hole to density, their answer would be termed "density-based model" abbreviated as DbM. Conversely, the answer is named "mass-based model" (MbM) when referring to mass or "volume-based model" (VbM) to denote volume. Furthermore, the mental models were categorized into levels according to Kurnaz & Eksi (2015) and Vosniadou & Ioannides (1998) and, specifically the initial model (IM), synthetic model (SyM), and scientific model (ScM), based on their characteristics, and followed by counting the average proportion of each level.

Findings

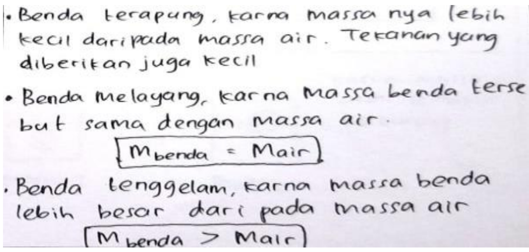
The following section shows the research findings based on themes that stand out for each context. Quotations from students' answers are presented in the form of pictures at the beginning only. For the other contexts, examples of students' answers are presented in Appendix A. The categorization of the identified mental models is included in the appendix.

Mental Models Related to the Determinant Factors of the State of Objects in Static Liquid Fluid

On the test sheet, one item required an open-ended answer by asking why an object is floating, suspending, or sinking. From this item, the data showed that most students referred to the ratio of the density of the object and water, while some described gravity and lifting force (buoyancy). Although the students in grades 5 and 6 only referred to the weight and mass of the object, a senior high school (for example: S11a) student described masses other than density (Figure 1). The answers have been translated and typed in Figure 1, while the original answer is next to it.

Figure 1

Example of the Student's Answer (S11a), Determinant Factors of the State of Objects in Water



An object floats because its mass is less than the mass of water
An object suspends because its mass is similar to the mass of water

$M_{object} = M_{water}$

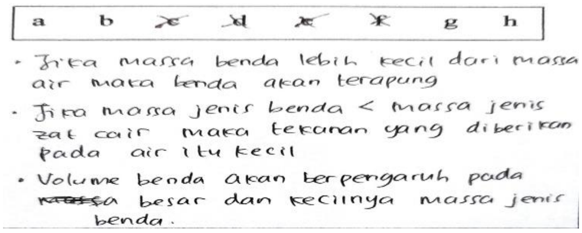
An object sinks because its mass greater than the mass of water

$M_{object} > M_{water}$

The consistency of the student's model was further confirmed through other items that required close-ended answer by providing several choices about the determinant factors for floating or sinking object. In the item about the causes of floating, suspending, or sinking, the dominant student was the DbM in the ScM category. However, some students adopted SyM by referring to weight, mass, volume, density, and gravity, in the items concerning the choice of the factors that caused floating or sinking. The example of the student's answer is presented in Figure 2.

Figure 2

Example of a Student's Answer (S11a), Determinant Factors of the State of an Object in the Water



- *If the object's mass is less than the mass of water, the object will float.*
- *If the density of the object < the density of water, then the pressure exerted on the water is small.*
- *The volume of the object will affect the density of the object.*

The assumed model by the student was categorized as SyM because it involved a conceptual model (ScM) and another representation in the IM category. Outcome space based on extracted data and generated themes is presented in Table 3.

Table 3

Findings for Determinant Factors for Floating, Suspending or Sinking Object (for Open-Ended Answers)

Model	Description	Primary	Junior	Senior	Undergraduate
Density-based model*	The density determines the state of the object		J8a‡, J8b, J8c, J8d, J8e, J8f, J8g, J9a, J9c, J9d, J9e, J9g, J9h	S11a‡, S11b, S11c, S11e, S11f, S11g, S11h, S11i, S12a, S12b, S12f, S12g, S12h	U1a, U2a, U2c, U2d, U3b, U3c, U3d, U4a, U4b, U4c, U4d
Gravity-based model*	The gravity determines the state of an object		J8a‡		
Buoyancy-based model*	The existence of buoyancy determines the state of an object			S11d, S11j, S12i	U1c, U1d, U2d, U3a
Hollow-existing model*	The presence or absence of hollow determines the state of an object		J8a‡	S12d	
Mass-based model◆	The state of an object depends on its mass	P5c	J8a‡, J8h, J9f	S11a‡, S12c, S12e	U1b, U2b
Weight-based model◆	The state of an object depends on its weight	P5a, P5b, P6a, P6b, P6c	J8a‡, J8h, J9b		
Surface area-based model◆	The state of an object depends on its surface area			S11a‡	

Note: *Scientific Model Category, ‡ Students adhered Synthetic Model Category (Scientific Model and Initial Model at the same time)◆ Initial Model Category, a, b, c… are the first, second, third…students in the same academic level.

The exploration of the mental model provides data on the extraction results. In exploring the factors which cause objects to float or sink with open-ended questions, it was found that the students dominantly adhered to DbM and the proportion in the ScM category also increased with academic level. The data also showed that none of the primary school students reviewed density as a determinant of floating or sinking to an object. Those adhered to the DbM regarding the cause of floating, suspending, or sinking were also generally adopted to the material-based model (MabM).

In the close-ended question format where the students were allowed to choose one or more factors that caused objects to float or sink, the data showed that none of the students in grades 5 and 6 considered the density variable. This finding was consistent with previous responses to open-ended question. Meanwhile, the proportion of students in grades 8 to 12 that considered the density concept instead of gravity increased, along with education. However, density did not appear to be a major factor in causing object to float or sink. Some students at this level considered the mass, weight, and volume of the object and even liquid. Also, some of these students attributed the density to the mass and volume represented in the formula $\rho = m/V$. Generally, there were differences in the proportion of students that adhered to a particular model concerning the two types of used items. For items that asked students to choose one or more variables, the number of students in the SyM category was more than the type of item that demanded open-ended answers. For example, in the open-ended question item, the number of students that adhered to MbM was nine, while twenty students chose the model in the closed item. The changes in this amount also occurred for the VbM and the weight-based model (WbM).

The weight of an object was considered a determinant of floating or sinking by giving the example that a light object will float while a heavy one will sink. This model was called WbM and a large proportion of the students adhered to it. Although there was a unique model where the weight variable determined the probability of an object to sink, the variable only applied to the factors that caused the sinking. It appeared that the students utilized the everyday understanding of the word "weight" (a variable) or "heavy" (a condition) as the state of the object in contrast to the word "light" and not as the quantity of force.

In exploring the factors that cause objects to float or sink with open-ended questions, it appeared that the students dominantly adhered to DbM and the proportion in the ScM category also increased with academic level. The data also showed that none of the primary school students reviewed density as a determinant of floating or sinking to an object. Those that adhered to DbM regarding the cause of floating, suspending, or sinking also generally adopted the material-based model (MabM). Although the used items do not explicitly state density, this model implicitly is DbM in the context of material versus shape. Meanwhile, some students adhered to DbM but ignored the material factor and instead considered shape as a determinant of the material's state in the fluid.

When they were asked about two objects of different shapes which are made from the same material, a balanced polarization (between material and shape) of the model was assumed by each student. The results can be seen in Table 4.

Table 4

Findings for Mental Model Related to Material Versus Shape

Model	Description	Primary	Junior	Senior	Undergraduate
Material-based model*	Identical material objects have the same state in water	P5a, P6a, P6b	J8b, J8d, J9a, J9c, J9d, J9e, J9f, J9g, J9h	S11j, S12a, S12b, S12d, S12g‡, S12h, S12i,	U1a, U1b, U1c, U1d, U2a, U2c, U2d, U3a, U3b, U3d, U4b, U4c, U4d
Volume-based model♦	The size/volume determines the state of the object			S11h, S12g‡	
Weight-based model♦	The weight determines the state of the object			S11h	
Shape-based model♦	The shape determines the state of the object. Regular objects will float while irregular ones have difficulty balancing and will sink easily, etc.	P5b, P5c, P6c	J8a, J8c, J8e, J8f, J8g, J8h, J9b	S11a, S11b, S11c, S11d, S11e, S11f, S11g, S11i, S12c, S12e, S12f	U2b, U3c, U4a

Although the used items do not explicitly state density, this implicitly model is DbM in the context of material versus shape. Meanwhile, some students adhered to DbM (based on data from Table 3) but ignored the material factor and instead considered shape as a determinant of the material's state in the fluid. Several statements exist concerning the shape-based model (SbM), including "objects with irregular shapes are difficult to balance, regular objects have a wider surface, hence, they easily float". Other statements are "there are many possible irregular states of matter, and the regular object is less likely to sink".

The proportion of students that adhered to DbM and *Shape-based Model* (SbM) was relatively the same, and these models were also adopted by all academic levels. There was a shifting in the proportion of students that embraced DbM to SbM, which illustrated that the shape of the object was a factor considered by some of the DbM students.

Table 5

Findings for Determinant Factors for Floating or Sinking Object, Which Utilized Close-Ended Answers and Permitted the Students to Have More Than One Choice

Model	Description	Primary	Junior	Senior	Undergraduate
Density-based model*	The density of the liquid determines the state of the object		J8a‡, J8d‡, J8e‡, J8f‡, J9a, J9d‡, J9e‡, J9f, J9g, J9h	S11a, S11b‡, S11c‡, S11d, S11f, S11g‡, S11h, S11i, S12a, S12b‡, S12c‡, S12d‡, S12e‡, S12h‡	U1a‡, U1b‡, U1c, U1d, U2a, U2b‡, U2c‡, U2d, U3a, U3b, U3d, U4b, U4c, U4d
	The density of the object determines the resultant state		J8a‡, J8b‡, J8c, J8d‡, J8e‡, J8f‡, J9a, J9b‡, J9c‡, J9d‡, J9e‡, J9f, J9g, J9h	S11a, S11c‡, S11f, S11g‡, S11h, S11i, S11j‡, S12a, S12b‡, S12c‡, S12d‡, S12e‡, S12f‡, S12g‡, S12h‡, S12i‡,	U1a‡, U1b‡, U1c, U1d, U2a, U2b‡, U2c‡, U2d, U3a‡, U3b, U3d, U4b, U4c, U4d
Gravity-based model*	Gravity determines the state of the object		J8a‡, J8d, J9d‡, J9e‡	S11b‡, S11f, S11g‡, S12b‡, S12e‡, S12h‡, S12i‡,	U2c‡, U4a
Mass-based model◆	The mass of the object determines the resultant state	P5c	J8a‡, J8e‡, J8f‡, J8g, J9b‡, J9c‡, J9d‡, J9e‡	S11b‡, S11g‡, S12b‡, S12c‡, S12d‡, S12e‡, S12h‡	U1a‡, U1b‡, U2b‡, U2c‡
Weight-based model◆	The weight of the object determines the state, as light objects float, while heavy one's sink	P5a, P6a, P5b, P6b, P6c	J8a‡, J8b‡, J8f‡, J8h, J9b‡, J9d‡	S11g‡, S12b‡, S12d‡, S12e‡, S12i‡,	U2c‡, U3c
Volume-based model◆	The volume of the object determines the resultant state (has a relationship with surface area)		J8a‡, J8c, J8d‡, J8e‡, J8f‡, J9c‡, J9d‡, J9e‡	S11c‡, S11g‡, S11j‡, S12b‡, S12d‡, S12e‡, S12f‡, S12g‡, S12h‡, S12i‡,	U1a‡, U1b‡, U2b‡, U2c‡
	The volume of the liquid determines the state of the object		J8a‡, J8e‡, J8f‡, J8g, J9b‡, J9c‡	S11g‡, S12b‡,	U2c‡, U3a‡

There were two items to explore whether the mental models possessed in the floating and sinking contexts affect the suspending state representation. In both items, the students were allowed to choose more than one option, along with examples. From these two items, data were obtained and extracted into several themes. The extraction result is presented in Table 5.

Table 5 also shows that the IM category is dominantly adopted by elementary school students while ScM is dominant by university students. The transition between the two, namely the SyM category is dominantly adopted by junior and senior high school students. Although items with close-ended answers did not provide an option for the surface area of the object, some students from the

VbM gave examples by relating them to volume and the "ease" of large-surface objects to float. Also, some of the students in this category understood that flat-plate-shaped objects, which are associated with a surface area that touches the water, are easier to float.

Mental Models Related to the Position of Suspending Object

The effect of the floating and sinking models adopted by the students on the suspending context was also studied, and the data extraction result is presented in Table 6.

Table 6

Findings for Mental Model Related to Depiction of Suspending Object

Model	Description	Primary	Junior	Senior	Undergraduate
Arbitrary model*	Varies between surface of the water and vessel base		J8g, J9f, J9g, J9h	S11a, S11f, S11h, S11i, S11j, S12c, S12g, S12i,	U1b, U1d, U2a, U2c, U2d, U3a, U3c, U3d, U4c, U4d
Middle model‡	In the middle of the depth	P5a, P5b, P5c, P6b	J8a, J8b, J8d, J8e, J8f, J8h, J9c, J9d, J9e,	S11c, S11e, S11g, S12a, S12b, S12e, S12f, S12h	U1a, U1c, U2b, U3b, U4a, U4b
Semi-floating model‡	Above the center and below the surface line	P6a	J9a	S11b, S12d,	
Floating model◆	On the surface	P6c	J8c, J9b	S11d	

Note. *Scientific Model Category, ‡ Synthetic Model Category, ◆ Initial Model Category

Table 6 shows almost 50% of the students depicted the suspending object in the middle. The students' representation of floating and sinking influenced the model adopted for the suspending context. Although the design of several items concerning the suspending context allowed the students to freely describe the position of the object, which was randomly opened between the surface and the base, it was done by a few students only. There were simplifications made by several students regarding suspending objects. As previously thought, the simplification consisted of depicting a suspending object in the "middle" of the water depth as a "middle way" for "between" the floating on the surface and the sinking at the base. The option of drawing in the center as a "middle way" or between the surface, termed "floating" and the base, called "sinking" was a form of this simplification. Consequently, this thinking behavior can be viewed as a *shortcut model*. The depiction of the suspending object as a *shortcut model* can be confirmed by data from Table 7 and Table 8.

Table 7

Findings for Mental Models Related to an Object near the Surface of the Water

Model	Description	Primary	Junior	Senior	Undergraduate
Suspending model*	The object suspends	P5a, P6a, P6b	J8a, J8b, J8f, J8g, J9c, J9g, J9h	S11a, S11b, S11c, S11g, S11j, S12b, S12d, S12e	U1b, U1d, U2c, U2d, U3a, U3b, U3c, U4b, U4d
Almost floating model ‡	The object floats or nearly floats or is between suspending and floating or $\rho < \rho_{water}$	P5b, P5c, P6c	J8c, J8d, J8e, J9a, J9b, J9d, J9f	S11d, S11e, S11f, S11h, S12a, S12c, S12h, S12i	U4a

Suspending object with ϱ < $ϱ_{water}$ model‡	The object suspends with a density less than that of water		J8h, J9e,	S11i, S12f, S12g	U1a, U1c, U2a, U2b, U3d, U4c

Table 7 shows around 50% of the students stated an object near the surface of the water is a suspending object (as Scientific Model). Almost 50% of them assumed that it is almost floating (or it was between suspending and floating) and it is a suspending object with its density less than the density of the water. Both models are embraced by these cross-grade students.

How were the context of an object near the base? Extracted data from students' answer is presented in Table 8.

Table 8

Outcome Space of Mental Models Related to An Object near the Base of Vessel

Model	Description	Primary	Junior	Senior	Undergraduate
Suspending model*	The object suspends	P5a	J8a, J8f, J9g, J9h	S11a, S11b, S11c, S11i, S11j	U1b, U1d, U2c, U2d, U4b
Semi-sinking model (suspending object with $ϱ_{object} > ϱ_{water}$ model)	The object suspends and almost, but is not quite sinking, the object suspends with a density greater than density of water		J8b, J8g, J8h, J9b, J9c, J9e, J9f	S11e, S12b, S12e, S12g, S12i,	U1a, U1c, U2a, U2b, U3a, U3c, U3d, U4a, U4c
Sinking model◆	The object sinks	P5b, P5c, P6a, P6b, P6c	J8c, J8d, J8e, J9a, J9d	S11d, S11f, S11g, S11h, S12a, S12c, S12d, S12f, S12h	U3b, U4d

Data from Tabel 8 shows that more than 50% of students adhered *semi-sinking* and *sinking model*. Some of them introduced density of the object related to the water. They stated that the object is suspending and almost (but is not quite) sinking with its density is greater than the density of the water. Some others firmly stated that the object is sinking. The students' statements confirmed how they described the position of the suspending object. A suspending object should be depicted in the middle and if it is out of the position then it can be categorized as floating or sinking.

Table 7 and Table 8 show that only a few students consistently stated that both objects near the surface of the water and the base of the vessel were suspending objects. The two tables also show the polarization of students for two conditions. Objects near the surface are described as floating or almost floating objects, while objects near the base are sinking or almost sinking. The unique aspect of the two tables is that when the data are related to the data in Table 6 where they are asked to draw a suspending object, there is no such polarization tendency. They dominantly drew the suspending object in the middle position of the depth, between the middle and the surface, or on the surface as if there is a limit to the position of the floating object, namely from the middle of the depth to the surface of the liquid.

Some students that previously assumed that objects near the surface were suspending, according to the scientific value, did not consider those near the base as sinking objects. This finding suggests that the ScM for suspending objects has not been fully and consistently used in all contexts. A sizable proportion of the students perceived stable objects near the base as sinking, "nearly" or "not very" sinking objects, and this model was adopted by students at all levels. Also, some students thought that these suspending objects had densities that were greater than that of water.

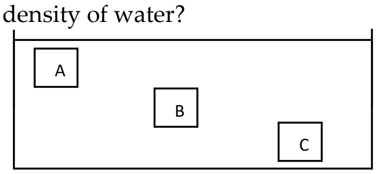
Model Mentals Related to Suspending Objects and Their Density

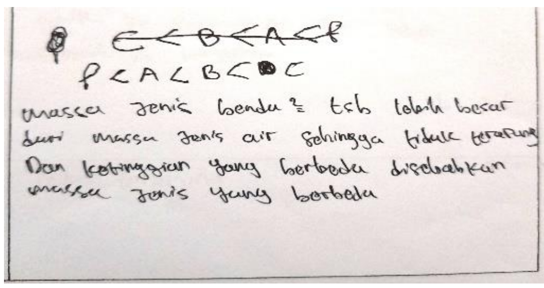
Two items were specifically designed to explore mental models relating to the position of suspending objects and their density. One item provided verbal information and were accompanied by pictures of three objects, A, B, and C, positioned differently in a vessel. Object A is drawn near the water surface line, B is in the middle of the depth, while C is near the base of the vessel, as shown in Figure 3. Another item, which was like the first one, provided information about the state of these three objects through description via text. In both items, the students were asked to explain the comparison of density between the three objects and water. An example of student's answer is presented in Figure 3, while Table 9 presents data from the extracted responses to these items.

Figure 3

Item about Suspending Objects in Different Positions, and Example of the S12e's Answer

Three objects, A, B, and C, are in a vessel filled with water. In a stable state, the three objects are in positions as shown. How do you think the density of objects A, B, and C will be, compared to the density of water?





$\rho < A < B < C$
The density of these objects is greater than that of water, therefore, they do not float and will have distinct heights due to different densities

Table 9

Findings for Mental Model Related to Comparison of the Density of Suspending Objects with Different Positions

Model	Description	Primary	Junior	Senior	Undergraduate
Suspending objects with the same density*	$\rho_A = \rho_B = \rho_C = \rho_{water}$		J9e, J9g, J9h	S11c, S11j	U1b, U1d, U2c, U2d
Suspending objects with different densities‡	$\rho_A < \rho_{water}$, almost floating; $\rho_B = \rho_{water}$, suspending; $\rho_C > \rho_{water}$, almost sinking or sinking		J8c, J8f, J9a, J9b, J9c	S11a, S11b, S11h, S12h	
	$\rho_A < \rho_B < \rho_C$ or $\rho_A < \rho_{water}$, $\rho_B = \rho_{water}$, $\rho_C > \rho_{water}$		J8a, J8b, J8d, J8e, J8g, J8h, J9d, J9f	S11d, S11e, S11f, S11g, S11i, S12a, S12b, S12c, S12d, S12e, S12f, S12g, S12i	U1a, U1c, U2a, U2b, U3a, U3b, U3c, U3d, U4a, U4b, U4c, U4d

The above themes are also confirmed by the item regarding the density ratio of the suspending object to water at different positions. It was interesting to identify from this level of SyM that students had "capital" density concept which showed their inconsistency, especially when associated with images of objects suspending at different depths. The suspending stable objects near the surface of the water were considered as "floating objects", "almost floating objects", or "suspending objects that were almost floating". Meanwhile, the suspending objects near the base of the vessel were considered "sinking objects", "near-sinking objects", or "suspending objects that were almost sinking". This assumption is supported by the argument that the densities of the objects are smaller or greater than the water. The ratio of the density of objects and water appeared to be dominant in determining the properties of objects suspending near the surface or base of the water. For students who did not consider density, their model did not use the term "almost" for the two conditions. They were firm on the choice between the three states of "floating", "sinking", or "suspending". Only nine students categorized the objects as suspending state based on the similarity of their density to the water density.

Mental Models of a Hole in a Suspending Object

The data extracted from the students' answers about the effect of making hole in a suspending object is presented in Table 10. Table 10 shows that there was a pattern adopted by some students concerning a suspending object with a hole, which will experience downward shifting and eventually sink. Making a hole is thought to cause water to enter the object, increase the mass, and allow it to sink. However, it was not considered that when a hole is made in an object, the change in mass accompanied by a proportional change in volume keeps the density constant. The students only focused on the formation of hole, which was interpreted as part of object that allowed water to enter. Concerning the model that was adopted for the floating object with a hole context, a review of the related data confirmed the information on the suspending object. Table 10 shows that more than 50% of the students thought that the water would enter a suspending object and cause it to sink if a hole is made in it. The event that a boat with a hole allowed water to enter it and make it sink, seemed to influence this process of reasoning. The model was occurred at all grades.

Table 10

Findings for Mental Models Related to Effect of a Hole on a Suspending Object

Model	Description	Primary	Junior	Senior	Undergraduate
Density-based model*	The object remains suspending, meaning the density does not change		J9e, J9f, J9g, J9h	S11g, S11j, S12a, S12d	U1c, U1d, U2c, U2d, U3a, U4b, U4c
Density-based model‡	The object will float, meaning the density decreases			S11f, S11h	U3b
Leaked boat model◆	The objects will sink as water enters	P5a, P5b, P5c, P6a, P6b, P6c	J8a, J8c, J8d, J8g, J8h, J9a, J9c, J9d, J9h	S11b, S11c, S11e, S11i, S12b, S12c, S12e, S12f, S12g,S12h, S12i	U1a, U1b, U2a, U2b, U3c, U4a, U4d
A hole as a floater model◆	The object will float		J8b, J8e, J8f, J9b	S11a, S11d	U3d

Note. ‡ Misapplication of DbM

Some students assumed that making hole has no effect on the state of suspending object. The students adhered DbM and can be categorized as ScM. When comparing the data for floating and sinking state, the proportion of students differed in the three contexts. This finding showed that the students did not consistently adopt one model. Hence, the mental model was not yet robust in structure and was still easily influenced by the phenomena presented, and DbM was not fully part of the responding and reasoning process.

Table 11 and Table 12 also show that more than 50% of students assumed the water as a sinker. They thought the existence of the hole makes the water enters the hole and leads the object to sinking. *Water as a sinker model* is like *the leaked boat model* and they can be categorized as IM. The model is consistently adhered by some students at all grades in the three contexts. In the context of a sinking state, the entered water keeps the object to be sinking.

Table 11

Findings for Mental Models Related to Effect of a Hole on a Floating Object

Model	Description	Primary	Junior	Senior	Undergraduate
Density-based model*	The object remains floating		J8b, J8f, J9a, J9f, J9g, J9h	S11a, S11h, S11j, S12b, S12d	U1b, U1c, U1d, U2b, U2c, U2d, U3b, U3d, U4a, U4b
Water as a sinker model◆	The object will sink because water enters the hole	P5a, P5b, P5c, P6a, P6b	J8a, J8c, J8d, J8e, J8h, J9b, J9d, J9e, J9h	S11b, S11c, S11e, S11f, S11g, S12a, S12c, S12e, S12f, S12g, S12h, S12i	U1a, U2a, U3a, U3c
	The object will suspend	P6c	J8g, J9c, J9h	S11d, S11i	U4c, U4d

Table 12

Findings for Mental Models Related to Effect of Hole on Sinking Object

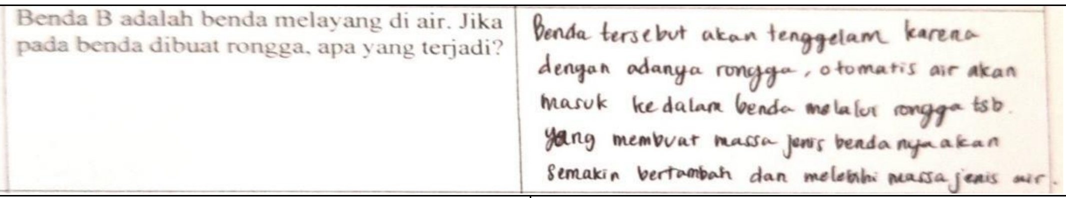
Model	Description	Primary	Junior	Senior	Undergraduate
Density-based model*	There is no change in the density of the object, therefore, it remains sinking		J9g		U1d, U2c, U2d, U3a, U3b, U4d
Water as a sinker model◆	The hole is filled with water, the mass or weight increases, and the object remains to sink	P5b, P5c, P6b, P6c	J8c, J8d, J8e, J8g, J8h, J9a, J9b, J9d, J9e, J9f, J9h	S11b, S11c, S11d, S11e, S11i, S11j, S12a, S12b, S12c, S12e, S12f, S12g, S12h, S12i	U1a, U1c, U2a, U2b, U3c, U4b, U4c
Air as a floater model◆	If no air enters, the object remains sinking		J8a, J8b		
Mass-based Model, hole as a floater◆	The objects will float because their mass decreases, depending on the size of the hole	P5a, P6a	J8f, J9c	S11a, S11f, S11g, S11h, S12d	U1b, U3d, U4a

Mental Models in the Context of the Hollow Suspending Object

The student's mental model concerning the treatment performed by making hollow in a suspending object was evaluated through an item. Meanwhile, example of the student's statement is presented in Figure 4, while the data extraction result from students' statements is displayed in Table 13.

Figure 4

Example of a Student's Statement (S12a) about the Effect of Hollow Making on a Suspending Object



Object B is an object suspending in the water. If a hollow is made in the object, what would happen?	The object will sink because with the presence of a hollow, water automatically will enter the object through the hollow, which makes the density of the object will increase and exceed the density of water.

Table 13 shows that there was a tendency for the pattern to play two roles concerning a hollow on suspending objects. Most of the students assumed that a hollow was a floater, while others considered it as a sinker. Those that adopted the floater model associated a hollow with reducing the mass or density of object, while the students that supported sinker linked it with the entry of water into the hollow, causing the object mass to increase. The adopted models were confirmed through the context of a hollow floating or sinking object. Meanwhile, the students dominantly adhered to the floater model, stating that a floating object either remained as it is or the activity increased. The students that adopted the sinker model in the context of suspending object were consistent with this model even though the situation changed. Conversely, students who were considered neutral in the context of suspending object predominantly adhered to the floater model concerning hollowed floating object, and vice versa regarding sinking object. Also, some students in the neutral category associated the sinker with the hollow, while others considered it to be the water. The two models can be related to the assumption that if there is a hollow, water will fill it and cause the object to sink. When comparing these representations with suspending models that possess hole, it appeared that some students equated the roles of hole and hollow in determining the state of objects in liquid. The model adopted by the students can be confirmed by making a hollow in a floating or sinking object, as seen in the findings displayed in Table 14 and Table 15.

Table 13

Findings for Mental Models Related to Effect of the Hollow on a Suspending Object

Model	Description	Primary	Junior	Senior	Undergraduate
Density-based model: hollow as floater*	The object will float because its density decreases		J9e, J9g	S11j	U1b, U2c, U2d, U3b
Hollow as floater model ‡	The object will float	P5a, P6b	J8b, J8h, J9c, J9d	S11c, S11e, S11h, S12d, S12e, S12g, S12h, S12i	U1a, U4c, U4d

	The object will rise to the surface as its mass decreases	P6c	J8d, J9a	S12b	
Neutral model‡	The object remains to suspend	P6a	J8e, J8f, J9b, J9h	S11a, S11b, S11f, S11g, S11i	U1c, U1d, U3a, U3c, U3d, U4a, U4b
Density-based model: hollow as a sinker‡				S12a	
Hollow as sinker model♦	The object will sink	P5b, P5c	J8a, J8c, J8g, J9f	S11d, S12c, S12f	U2a, U2b

Table 13 shows that there was a tendency for the pattern to play two roles concerning a hollow on suspending objects. Most of the students assumed that a hollow was a floater, while others considered it as a sinker. Those that adopted the floater model associated a hollow with reducing the mass or density of object, while the students that supported sinker linked it with the entry of water into the hollow, causing the object mass to increase. The adopted models were confirmed through the context of a hollow floating or sinking object. Meanwhile, the students dominantly adhered to the floater model, stating that a floating object either remained as it is or the activity increased. The students that adopted the sinker model in the context of suspending object were consistent with this model even though the situation changed. Conversely, students who were considered neutral in the context of suspending object predominantly adhered to the floater model concerning hollowed floating object, and vice versa regarding sinking object. Also, some students in the neutral category associated the sinker with the hollow, while others considered it to be the water. The two models can be related to the assumption that if there is a hollow, water will fill it and cause the object to sink. When comparing these representations with suspending models that possess hole, it appeared that some students equated the roles of hole and hollow in determining the state of objects in liquid. The model adopted by the students can be confirmed by making a hollow in a floating or sinking object, as seen in the findings displayed in Table 14 and Table 15.

Table 14

Findings for Mental Models Related to Effect of the Hollow on a Floating Object

Model	Description	Primary	Junior	Senior	Undergraduate
Density-based model: hollow as a floater*	The object will float more because its density decreases		J9g		U2d
Hollow as a floater model‡	The object will float	P5a, P6a, P6b	J8b, J8e, J8f, J8h, J9a, J9b, J9c, J9h	S11a, S11b, S11c, S11e, S11f, S11h, S11i, S12b, S12d, S12e, S12g, S12h, S12i	U1a, U1c, U1b, U2a, U2b, U2c, U3a, U3b, U3c, U4a, U4b, U4c, U4d
	The object will float more		J8d, J8g, J9e	S11j, S12c	
Hollow as a sinker model♦	The object will suspend or sink	P5b, P5c, P6c	J8a, J8c, J9d, J9f, J9h	S11d, S11g, S12a, S12f	U1d, U3d

Table 15

Findings for Mental Models Related to Effect of the Hollow on the Sinking Object

Model	Description	Primary	Junior	Senior	Undergraduate
Density-based model: hollow as a floater*	The object will shift to the surface because the density decreases		J8d, J9e, J9g,	S11f, S11j, S12c	U1c, U2c, U2d,
Hollow as floater model‡	The object will float	P5a, P6a, P6b	J8b, J8e, J9a, J9b	S11a, S11c, S11d, S11e, S12g, S12i	U1a, U1b, U2b, U3d, U4c, U4d
	The object will suspend	P5b, P5c, P6a	J8c, J8f, J8g, J9c	S11a, S11e, S11g, S11i, S12g, S12i	U3b, U3c
Hollow as a sinker model♦	The object will sink	P6c	J8a, J8h, J9d, J9f, J9h	S11b, S11h, S12a, S12b, S12d, S12e, S12f, S12h	U1d, U2a, U3a, U4a, U4b

Table 14 and Table 15 show that most students adhered to the model that a hollow is a floater for both floating and sinking objects. Unfortunately, only a small number of students can be categorized into the scientific model which examined density and linked it to the hollow as a factor that determines the state of an object. Some of them adhered to the *hollow as floater model* but cannot be categorized into ScM because they have not linked the existence of a hollow that causes a change in the density of the object.

Effect of Filling Air into the Hollow of the Suspending Object

The data on the effect of filling air into the hollow of a suspending object were studied through items concerning suspending, floating, and sinking objects. Meanwhile, the floating and sinking contexts were provided to confirm the extent of their relationship with the suspending model. The data extraction result from the students' responses is presented in Table 16.

Table 16 shows that the students dominantly considered water as a floater model and did not regard the object state described in the questions as hollow suspending objects with fixed volumes. Also, they did not consider that filling the hollow with air caused mass gain but viewed it as an entity that caused objects to lift upward. However, some students embraced this model by building the argument that the addition of air causes a decrease in density since the density of air is less than that of water. The students dominantly regarded air as a factor that changed an object's state from sinking to suspending or floating, from suspending to floating, and an increased tendency to float. A fairly large proportion of students, at over 50%, adhered to the model that objects with air-filled hollow tended to move upward. Meanwhile, a student referred to density but compared air density with that of water and further expressed that an object's state changed in water after the hollow was filled with air. Hence, when the air was the filler, there was a shifting of objects from floating to "more floating" as well as sinking or suspending to floating. This shifting occurred because air is a factor that "lifts" objects to a higher position than the base of the vessel.

Table 16

Findings for Mental Models Related to Effect of Air Filling on the Hollow of the Suspending Object

Model	Description	Primary	Junior	Senior	Undergraduate
Air as a sinker model*	The object will sink as the mass or density increases		J8h, J9c	S12g, S12i	U1b, U2a, U2d, U3c
Neutral model‡	The object remains to suspend	P5b, P5c, P6a, P6c	J8c, J8e, J9h	S11b, S11d, S11g, S12d	U1c, U3a, U4a, U4b

Air as a floater model♦	The object will float, as the density is reduced by air. The density of air is less than the density of water		J8a, J9e	S11j, S12c	U2b
	The object will float	P5a, P6b	J8b, J8f, J9a, J9b, J9d, J9f, J9g, J9h	S11a, S11c, S11e, S11h, S11i, S12a, S12b, S12e, S12f, S12h	U1a, U1d, U2c, U3b, U3d, U4c, U4d
	The object rises to the surface because it gets lift force by air		J8d, J8g	S11f	

A small proportion of students thought that the addition of air to the hollow caused objects to slide downward and perceived it to increase the density of the object. Meanwhile, some stated that the object was shifting downwards but referred to the change in the object's mass. However, no student explained the relationship between changes in mass and density.

The consistency of the students is confirmed with the floating and sinking objects. The data in Table 17 and Table 18 show that the *air as floater model* was dominantly adopted by the students. Meanwhile, most of the students who adopted this model for the suspending phenomenon also accepted it in the floating and sinking contexts.

Table 17 and Table 18 show that *air as a floater model* was consistently adhered by some students from all grades for both contexts. The students dominantly regarded air as a factor that changed an object's state from sinking to suspending or floating, from suspending to floating, and an increased tendency to float. The air is considered as a factor as well as an active force that lifts objects upwards, but the views are on air and water. Possibly, the students imagined the nature of a hot air balloon which seemed to appear "lighter" when filled with hot air and did not consider the latter case that the balloon's density decreased due to the filling. This situation is different from a hollow or fixed-volume object filled with neutral air.

Table 17

Findings for Mental Models Related to Effect of Air Filling on the Hollow of Floating Object

Model	Description	Primary	Junior	Senior	Undergraduate
Density-based model*	The object will move down as the density increases		J9c	S12i	U2d, U3b
Mass-based model*	The object will suspend or sink as the mass increases		J8a, J8h	S11f, S12g	U1b, U3c
Air as a sinker model*	The object will suspend because of the air push			S11a, S11d	
	The object sinks	P5c, P6b, P6c		S11b, S11h, S11j	U1c, U1d
Air as a floater model‡	The object floats because the density of air is less than that of water		J9e	S11e, S11i, S12a, S12b, S12c, S12d, S12e, S12f	U1a, U2b, U3a, U4b, U4c
Air as a floater model♦	The object remains floating	P5a, P5b, P6a	J8b, J8c, J8d, J8e, J8f, J8g, J9a, J9b, J9d, J9f, J9g, J9h	S11c, S11g, S12h	U1c, U2a, U2c, U3d, U4a, U4d

Table 18

Findings for Mental Models Related to Effect of Filling the Air on the Hollow of the Sinking Object

Model	Description	Primary	Junior	Senior	Undergraduate
Density-based model*	The object remains sinking as the mass and consequently, the density increases		J8h	S11b, S11e, S11j	U1d, U2d
Air as a sinker model‡	The object remains sinking		J9h	S11h, S12a, S12d, S12e, S12g, S12h, S12i	U1b
Air as a floater model♦	The objects will float, as the air, which is lighter than water, lifts the object	P5b	J8c, J8f, J8g, J9c, J9e	S11a, S11f, S11g	U2a, U3a, U3b, U3c, U4b
	The air lifts the object	P5a, P5c, P6a, P6b, P6c	J8a, J8b, J8d, J8e, J9a, J9b, J9d, J9f, J9g	S11c, S11d, S11i, S12b, S12c, S12f	U1a, U1c, U2b, U2c, U3d, U4a, U4c, U4d

Effect of Adding the Volume of Liquid

The effect of increasing the volume of liquid on the state of the object was evaluated through an item that presented a picture of a suspending object positioned in the middle of the liquid's depth. Then, the students were asked to predict the state of the object after the water was added in the vessel. The result of this data analysis is presented in Table 19.

Table 19

Findings or Mental Models Related to Effect of Increasing Liquid Volume on the Vessel toward a Suspending Object

Model	Description	Primary	Junior	Senior	Undergraduate
Neutral Model‡	The object suspends at a height, but there is no change of position				U2d
Middle model‡	The object suspends at a height, following the water level, but still in the middle of the depth	P5a, P5c	J8c, J8d, J8e, J8g, J8h, J9d, J9e, J9f, J9g, J9h	S11a, S11c, S11e, S11g, S11i, S11j, S12a, S12d, S12e, S12f, S12g, S12h, S12i	U1a, U1d, U2a, U2c, U3a, U3b, U3c, U3d, U4a, U4b, U4c, U4d
Water as a lifter model‡	The object approaches the surface	P5b	J8f, J9c	S11b, S11d, S11f, S11h	U1b, U1c, U2b
Water as a lifter model♦	The object is on the surface		J8b, J9a, J9b	S12c	
Water as the downward pusher model♦	The object is close to or is at the base of the vessel	P6a, P6b, P6c	J8a	S12b	

Table 19 shows that over 50% of the students stated that adding water to a vessel where there was a suspending object in the middle of the depth meant that the object was still suspending there. This finding reinforced the *middle model* obtained in previous data (Table 6) and adopted by the students, which specifically indicated that the position of a suspending object "must" be in the middle of the depth. However, several students drew objects close to the surface, while a small number described the position of the object to be near the base of the vessel. Some students assumed that the suspending object model did not have to be in the middle of the depth, while the remaining students drew always in the middle position. The tendency to depict a suspending object in the middle of the liquid depth, carried out by students for all grades with a fairly large proportion. This confirms the previous preliminary finding in learning activity.

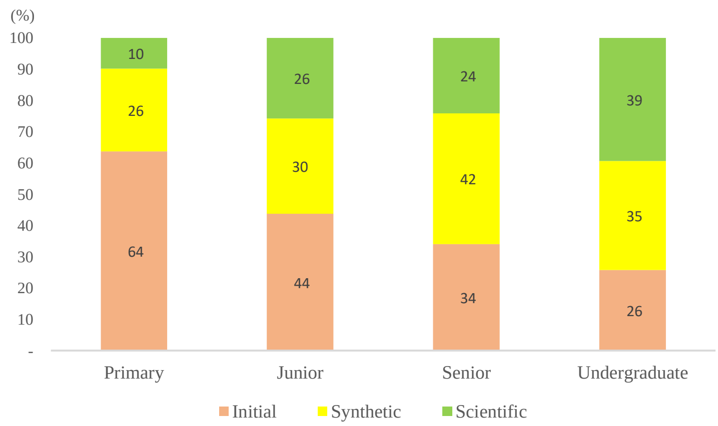
Summary of the Findings

The data in Table 3-Table 19 are then summarized into Figure 5 to get an overview of the general trend, especially to see the average proportion of students who are in the category of scientific, synthetic, and initial mental models. Determination of the average proportion by combining all the data from the 17 tables based on the students' position related to the type of mental model adopted in each context.

Figure 5 shows a tendency of the average proportion of students in the IM, SyM, and ScM categories to form a mental model hierarchy according to the grade of the students. The IM level is dominantly occupied by students from the primary school. In contrast, the ScM level is adhered by university students with the largest proportion. The SyM level as a transition from IM to ScM with the largest proportion occupied by students from high school. The figure also shows that the order of proportion from highest is IM, SyM and ScM.

Figure 5

Summary of the Findings Based on Categories of Mental Models



Discussion

The exploration of the mental model provides data on the extraction results, as presented in the previous section. The data in Table 3 to Table 19 show that the mental model adopted by students is highly dependent on the context of the phenomena presented. Although, the mental model in the ScM category is dominantly adopted by students in reviewing the factors that cause an object to float, suspend or sink, the model (e.g DbM) is inconsistently applied to respond to phenomena in some contexts. The concept of density as a capital (for DbM students) was still influenced by the shape, surface area, the presence of a hole, hollow, air filling in the hollow, and change in the height of the liquid. The findings are also found in other studies (Duit, 2007; Minogue et al., 2015; Minogue & Borland, 2016; Smith et al., 1997) and they can be categorized as an intuitive model, alternative conception, or misconception (Yin et al., 2008). Similar models related to the heavy or light object have been discovered in previous studies (Havu-Nuutinen, 2005; Yin et al., 2008).

The students in grades 5 and 6 only considered the object's weight and mass in reviewing the factors that cause an object to float, suspend or sink. This finding is related to the curriculum at the elementary school level in Indonesia (Curriculum 2013), which does not introduce the concept of density. Hence, there are no instructional interventions that shape their mental models towards ScM related to density. Conversely, some students in grades 8, 9, 11, and 12, and even university students considered density but still left mass, volume, and weight variables. The adopted model, which can be categorized as SyM and is the existing ScM mixed with IM elements, confirmed that SyM is a transition model from IM to ScM. This model contains scientific aspects and IM "residues" as well. The term "residue" is used to state that a conception containing misconceptions as an alternative model is difficult to completely change (Yin et al., 2008).

The implication of the students' inconsistency in activating their model mental aspects related to DbM can be seen in the depiction of the position of the suspending object. The depiction of suspending objects in the middle of the depths is not entirely a mistake or misconception. The perspective of representational flexibility (Deliyianni et al., 2016) shows that there is rigidity in thinking in terms of representation or functional fixedness (Matlin, 2009), so that the suspending objects are in the middle. This thinking behavior can be related to the pattern found by Gette et al. (2018), which showed that some students adopted *the descending line model* in reasoning cases of five objects with different masses. The five objects drawn sequentially in water formed a descending line based on the mass of the object. From an instructional aspect, this model was probably generated from the habit of teachers or textbooks to present suspending objects in the middle of the water depth. The lack of variation in the presentation can build a mindset that suspending objects were often located, as seen in instructional activities and textbooks. Without adequate explanation, coupled with a lack of facts available in nature about suspending object entities, learner can develop personal representations, known as the student's model. Although they considered fish in a pond or aquarium as well as imagined a submarine as a suspending object, the understanding of how this happened was not a concern in the curriculum (Gette et al., 2018). As a result, the student's model is improvised and does not lead to ScM.

A suspending object does not have to occupy the middle of the depth of the liquid. Drawings are to be expected with random positions between the surface and the base of the vessel. Even if there are students who describe a suspending object at the base accompanied by an explanation that an object is a suspending object that is at the base, it is a model that should be appreciated as a scientific model. Especially if the description is associated with a review of the density of object and the density of liquid fluid. DbM adopted for the floating and sinking contexts by some students was insufficient to build the suspending mental models in the ScM category.

The insufficiency to build the mental models for reasoning and visualization can be considered as a gap in the consolidation of their mental models (Bongers et al., 2020). It was still "fragile" easily affected by suspending contexts, and the cognitive elements owned were not connected constructively to build a scientifically acceptable target model. Referring to the definition that a mental model is a structured building consisting of cognitive elements and fundamental knowledge, which are generally referred to as resources (Hammer, 2000) or associated aspects (Mansyur et al., 2020). However, according to this definition, the mental models adopted by the students in this study contained elements that were not strongly connected, and thus, did not lead to the appropriate and scientifically acceptable representation. Study by Vosniadou and Ioannides (1998) showed that an individual derives or produces mental models based on the knowledge and so, can assimilate or bring together new information.

The resulting mental model must be applied and tested in new situations and maintained for a long time by the individual who built it (Coll & Treagust, 2003) to shift it towards a scientific model.

The statement can be confirmed based on the summary of overall data that the proportion of IM level tends to decrease, at the same time, proportion of ScM level is a vice versa. Based on the students' grade, there is a decrease in the initial mental model and an increase in the scientific mental model starting in grade 8. This is different from the findings of Kurnaz & Eksi's (2015) study where the transition occurred in grade 11 for the context of solid friction. The difference related to the curriculum implemented, especially about the concepts that underlie each model. The transition occurred in grade 8 is thought to be related to the concept of density as a fundamental concept was introduced at that level. This confirms the influence of the curriculum and the environment on the development of students' mental models.

Conclusion

Based on the findings and descriptions above, it can be concluded that the students' mental models were generally still in the initial and synthetic model and were also very context dependent. Some students were at the scientific model level for certain contexts related to the phenomena of suspending objects but remained at the synthetic or initial levels for others. Mental model levels were also observed in general to depend on the grade of the students, confirmed the influence of the curriculum and environment. The synthetic level as a transition from initial to scientific model with the largest proportion occupied by students from high school.

There was a tendency that the mental models adopted by students in the floating and sinking contexts affected the assumed suspending phenomenon. Also, there was a shortcut and simplification model pattern related to the depiction of suspending objects by only choosing the condition between floating and sinking. These patterns were chosen without reviewing the substantial aspects of the suspending phenomenon regarding the concept of density.

Consequently, teaching the concept of floating and sinking without giving sufficient portions for the concept of suspending objects is not enough. The assumption that by handling of these two concepts automatically meant the suspending object phenomenon is also evaluated, seemed to be rejected based on the findings of this study.

The positions of suspending objects in liquid presented in textbooks and classroom learning activities need to be varied in the area between the surface line and the base of the vessel. Moreover, the placement of suspending objects at the base can be done by adding an explanation that "these objects are suspending at the base". The substantial aspect of the density concept needs to be emphasized to reduce the initial and synthetic models. Finally, further studies can be performed by taking respondents proportionally based on the levels in a better order so that the transition can be known more firmly.

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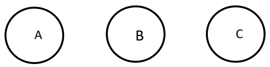
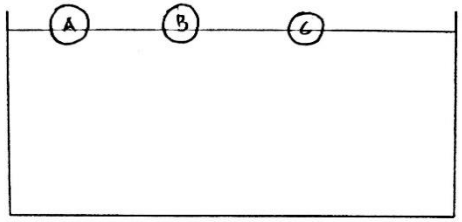
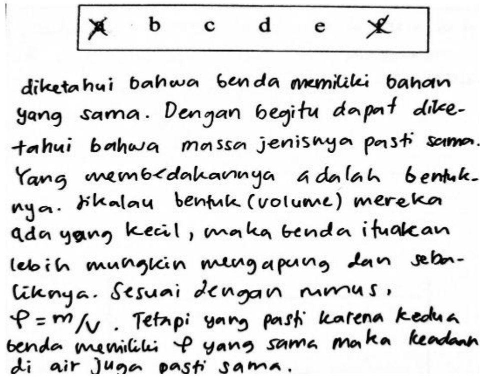
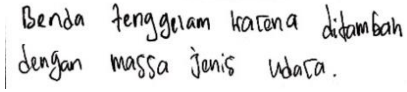
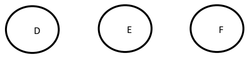
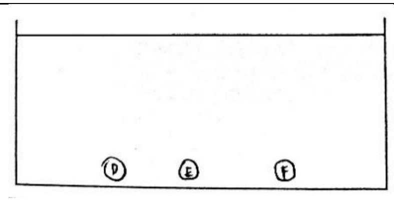
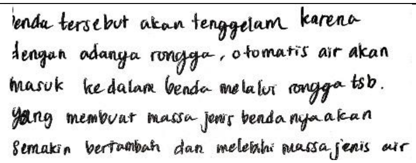
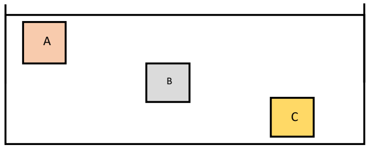
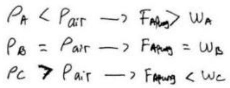
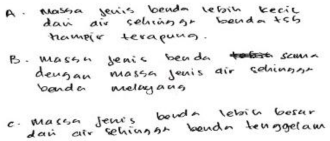
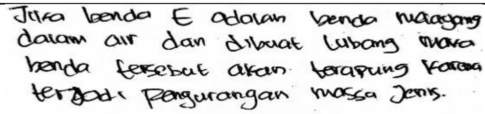
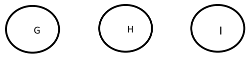
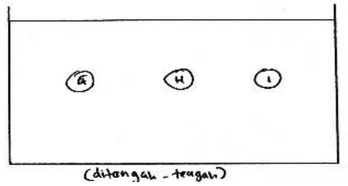
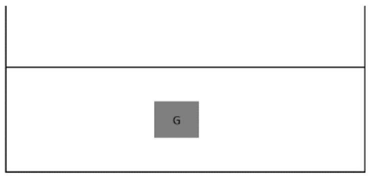
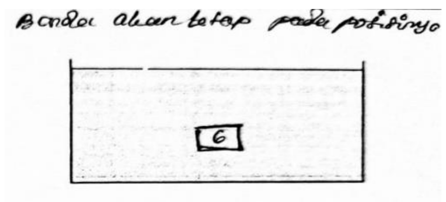
Appendix A

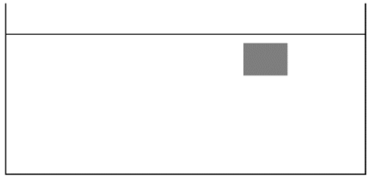
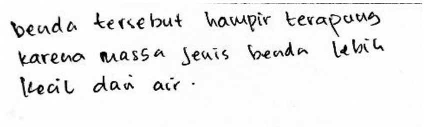
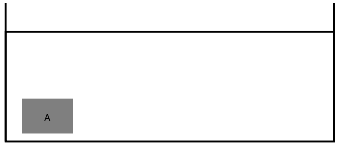
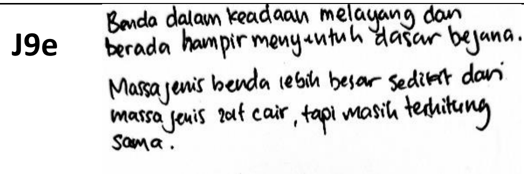
Sample of the test items, students' answer, and categorization.

No.	Problem	Sample of students' answer (and translation)	Remark	Category
1	The following three objects are floating on water. Draw the possibilities of the objects' position. 	J8e 	The student depicted the floating object at the liquid's surface.	Scientific Model
2	Objects A and B are of the same material but have different shapes. Object A is box-shaped, and Object B is irregular in shape. The correct statement about the possible positions of the two objects in water is (it is possible to choose more than one if needed). a. Object A suspends, Object B suspends b. Object A suspends, Object B sinks c. Object A sinks, Object B floats d. Object A sinks, Object B sinks e. Object A floats, Object B sinks f. Object A floats, Object B floats Give reasons toward each of your choices!	S12g  (It is known that objects have the same material. The density must be the same, the difference is the shape. If their shape (volume) is small, then the object will be more likely to float and vice versa, according to the formula $\rho = m/V$. What is certain is that because both objects have the same density then the state in water must also be the same).	The student considered the material and density of the objects but also considered the volume of the objects. He can be categorized to synthetic model.	Density-based model (Scientific Model) Volume-based model (Initial Model)

No.	Problem	Sample of students' answer (and translation)	Remark	Category
3	A hollow object is floating on water. If the hollow is filled with air, what will happen?	S12i  Benda tenggelam karena ditambah dengan massa jenis udara. (The object will sink because there is an addition of air density)	The student stated that the addition of the air increases the total density.	Density-based model (Scientific Model)
5	The following three objects are sinking in water. Draw the possibilities of the objects' position. 	J8e 	The student depicted the sinking object at the base (although it does not touch the base, it can be categorized as at the base; it can be compared with other depictions).	Scientific Model
7	Object B is an object suspending in water. If a hollow is made in the object, what will happen?	S12a  enda tersebut akan tenggelam karena dengan adanya rongga, otomatis air akan masuk kedalam benda melalui rongga tsb. yang membuat massa jenis bendanya akan semakin bertambah dan melebihi massa jenis air (The object will sink because with the presence of a hollow, water automatically will enter the object through the hollow, which makes the density of the object will increase and exceed the density of water)	The student assumed that the hollow is a path for water to enter the object, so that its density will increase.	Hollow as a sinker model Water as a sinker model Density-based model (Synthetic Model)

No.	Problem	Sample of students' answer (and translation)	Remark	Category
12	Three objects (A, B and C) are in a vessel filled with water. In a stable state, the three objects are in positions as shown. How do you think the density of objects A, B and C compared to the density of water?  	**S12i**  (air = water; apung = buoyancy) **S11h**  A. The object density is less than the water so that it is almost floating. B. The object density equals the water so that it is suspending. C. The object density is less than the water	S12: A is an object with density less than the water's density. A buoyancy greater than its weight. - B is an object with density equals the water density. A buoyancy equals its weight. - C is an object with density greater than the water density. A buoyancy less than its weight. For other items, the student used term "almost" or "a suspending object that is almost floating/suspending".	- A is an almost floating object. - A is a suspending object with $\varrho < \varrho_{water}$. - C is a suspending object. - C is a semi-sinking model (suspending object with $\varrho_{object} > \varrho_{water}$ - C is a sinking object (Synthetic Model) - B is a suspending object (Scientific Model)
13	Object E is a suspending object in water. If a hole is made in the object, what would happen?	**U3b**  (If object E is a suspending object in water and a hole is made then the object will float due to a reduction in density).	The student considered the reduction of object's density without considered the reduction of its mass and volume in the same time (there is no change of its density).	Density-based model (misapplication) (Synthetic Model)

No.	Problem	Sample of students' answer (and translation)	Remark	Category
14	The following three objects are objects suspending in water. Draw the possibilities of the objects' position. 	J8e  (At the middle)	The student depicted the objects at the middle of the depth. He emphasized that the object is at middle. Although the depiction can be categorized correctly, it remains rigidity of representation. The suspending object does not have to be at the middle.	Synthetic Model
16	Object G is in the water in the position as shown. If the water in the vessel is added so that the vessel is almost full, what would happen? Draw the position of the object! 	U2a  (The object is still at its position)	The student depicted the object at the middle of the depth. He emphasized that the object is at the position (middle) after the water addition. The object suspends at a height, following the water level, but still in the middle of the depth. Although the depiction can be categorized correctly, it remains rigidity of representation. The suspending object does not have to be at the middle.	The Middle Model (Synthetic Model)

No.	Problem	Sample of students' answer (and translation)	Remark	Category
17	The object in the vessel filled with water is in the position as shown. How do you think the object is? Give explanations! 	 (The ob ject is almost floating because its density is less than the water's density).	The students in this category combined the object's position and density but it remained contrary.	Almost floating model Semi-floating model (Sinthetic Model)
22	The object is stable in the vessel as shown. How do you think the object is? Give explanation! 	 (The object is suspending, and it is almost touching the vessel base). (The object's density is greater than the liquid's density, but it is still assumed the same.)	The students in this category combined the object's position and density but it remained contrary.	Almost sinking model The semi-sinking model (Synthetic Model)

No.	Problem	Sample of students' answer (and translation)	Remark	Category
24	Based on your opinion, what do aspects determine the state of a floating object? You may choose more than one if needed. Give an example of each of your choices! a. Weight of the object b. Gravity c. The mass of the object d. The density of the object e. Density of the liquid f. The volume of the object g. Volume of liquid Give a reason to each of your choices!	**S12i** a (b) c d (e) (f) g h b. Gaya gravitasi yang besar, sehingga F_A bernilai besar. e. Telur di air garam akan mengapung karena ρ_{air} lebih besar. f. Bola yang lebih besar akan mengapung karena F_A akan bernilai besar. Saya memilih tiga komponen ini, karena merupakan komponen F_{Apung}. b. The gravity is great so that F_A is great value. e. Egg in the salt water will float because ρ_{water} is greater. f. A bigger ball will float because F_A is great (F_A = buoyancy). I am choosing the three components because they are buoyancy's component.	The student considered the gravity and the density as aspects related to a state of an object (scientific model), but at the same time he considered the size of the object (initial model). He can be categorized to synthetic model.	Gravity-based model (Scientific Model) Density-based model (Scientific Model) Volume-based Model (Initial Model)
27	An object has a hollow is suspending in water. If the hollow is filled with air, what will happen? Explain!	**J8d** benda tersebut akan naik ke atas karena mendapat gaya angkat (The object will shift upward because there is a lifting force-buoyancy).	Student assumed that air is an active force to lift the object.	Air as a floater (Initial Model)