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Students' External Representation Patterns of Suspending Objects in Static Fluid

Jusman Mansyur* 

Tadulako University, INDONESIA

I Komang Werdhiana 

Tadulako University, INDONESIA

Darsikin Darsikin 

Tadulako University, INDONESIA

Sarintan N. Kaharu 

Tadulako University, INDONESIA

Nurgan Tadeko 

Tadulako University, INDONESIA

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Abstract: This study aims to explore the pattern of external representation of suspending objects in a static fluid. The study used a qualitative descriptive method involving 57 elementary, junior, senior school, and university students. Data collection implemented a 30-item test covering the dominant context of suspending and partially floating and sinking. Some of phenomenographic steps were adapted in data analysis. Based on the data analysis, it can be concluded that there is a dominant external representation pattern, where there is a simplification of the depiction of suspending objects. Suspending position tends to be locked in a limited area, namely in the middle of the depth of the liquid. In the context of suspending objects' cuts, the cuts were generally represented by an upward shifting pattern. Factors that influence the pattern of representation are the involvement of intuition in conceptualizing the phenomena presented, and the conceptual aspect of density has not been integrated into the reasoning process for compiling external representations, both diagrams, and texts. Research limitation is presented in this article.

Keywords: *External representation pattern, floating, sinking, static fluid, suspending.*

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Introduction

Research in cognitive psychology shows that most common reasoning patterns result from different pathways and are associated with the interaction between two cognitive processes, namely the heuristic process and the analytic process. If a person is faced with a particular situation or task, the first process is immediately and unconsciously developing a mental model of the situation based on knowledge and experience, contextual cues, relevance, and other factors. This "available first" mental model is often a quick and unconscious attempt by a reasoning person to develop a coherent and reasonable way of thinking about the situation at hand (Gette et al., 2018). In this case, mental models are internal representations of objects, circumstances, sequences of events or processes, and relevant psychological and social actions. Mental model and representational aspect and meta-representational skills have been the subject of some studies in physics education (Kohl & Finkelstein, 2005).

Based on Mayer's theory (Canlas, 2019), an essential aspect of the learning process is a visual representation, which is the externalization of information as a visual model such as visual representations (e.g., diagrams, symbols, text, etc.) commonly called external representations. The external representation can be a sequence of words to describe the internal representation. It can also be a picture or a list of information that includes specific elements of the internal representation (Solaz-Portolés & Lopez, 2007). Based on this framework, it can be stated that visual representations such as diagrams and resulting text allow us to access a person's mental model of a phenomenon. This explains that diagrams and words (produced orally and literally) used simultaneously can improve cognition and mental model construction (Canlas, 2019).

Research in science education has examined students' thinking behaviour about phenomena, such as objects floating in the water while other objects sinking (Duit, 2007). Loverude et al. (2003) asserted that standardized learning leaves the

* **Corresponding author:**

Jusman Mansyur, Tadulako University, Indonesia. ✉ jusman_mansyur@untad.ac.id



learners' inability to predict and explain the floating and sinking behaviour of simple objects. Kohn (1993) found similarities between children and adults in characterizing floating or sinking objects. Minogue and Borland (2016) reported that students often only review one quantity: mass, weight, volume, or shape. Another study found that high school students used an intuitive approach in predicting floating or sinking objects (Smith et al., 1997). The research of Castillo et al. (2017) related to students' prediction about the state of an object in a liquid. Chien et al. (2009), Havu-Nuutinen (2005), Shen et al. (2017), Shivakumar (2016), and Teo et al. (2017) examined the concepts of properties and states of objects in liquids. In the context of learning, Qonita et al. (2019) examined process skills in instilling the concept of floating and sinking. There are also studies (Kafiyani et al., 2019; Viyanti et al., 2017) which each developed assessment tools and a diagnostic test to explore students' mental models of static fluids.

Based on the description above, it appears that there has been no research that specifically examines suspending objects. On the other hand, a case was found by the first author in School Physics lecture when students were asked to describe the position of an object in a liquid. There is a pattern tendency that the external representation of suspending object. It is positioned simplistically in the middle of the depth of the liquid (Kaharu & Mansyur, 2021). Because the floating is on the surface and sinking at the base, suspending is in the middle between the two. These findings require further study to investigate whether this pattern is consistent across a broader scope. The consistency can be seen from the pattern of external representation of suspending in various contexts. The study is also directed to explore the factors that cause external representation patterns and the possibility that the context of floating and sinking influences these patterns. Exploration of the pattern was carried out through a cross-sectional study.

Several researchers have carried out studies on aspects such as conceptions, misconceptions, and mental models of phenomena with cross-sectional studies. For example, Türk et al. (2015) explored grades 5 to 8 students' mental models on climate change. They found that students had alternative conceptions and mental models that did not match scientific explanations. Çepni and Keleş (2006) examined students' cross-age conceptions of electrical circuits and found that a certain age dominantly adopted specific mental models. Other researchers such as Coll and Treagust (2003), Gönen and Kocakaya (2010), Kurnaz and Eksi (2015), Lin (2017), Sahin et al. (2008), Vosniadou and Brewer (1992), and Vosniadou and Ioannides (1998) also applied a cross-sectional study which illustrated that this approach is quite widely used to explore the influence of cognitive development as well as the influence of the curriculum and the environment. However, no cross-sectional study has examined the external representation pattern, especially in the case of suspending objects in liquid fluids.

Research questions

Based on the description above, the research questions:

- How was the pattern of the learner's external representation of suspending objects in a static fluid?
- What factors affected the pattern of the external representation of suspending objects in a static fluid?

Methodology

Research Design

This research is qualitative research using a descriptive-qualitative design. This study distinguishes between cross-age studies, which usually examine cognitive development, and cross-grade studies that examine the influence of the curriculum and the environment (Lin, 2017). Respondents were selected based on the academic level so that this study is categorized as a cross-grade study. Thus, an embodied conception in the external representation pattern is considered the influence of the curriculum and the environment

Respondent

The respondents of this study were elementary, junior high, high school students, and prospective physics teacher students. The respondent's identity is kept secret by using an initial or pseudonym in the form of a code. The description of respondents is presented in Table 1.

Table 1. Description of Respondent

Grade	Code	Number of students
Primary school-Grade 5	R5	3
Primary school-Grade 6	R6	3
Junior Secondary School-Grade 8	R8	8
Junior Secondary School-Grade 9	R9	8
Senior High School-Grade 11	R11	10
Senior High School-Grade 12	R12	9
Undergraduate-Year 1	RU1	4
Undergraduate-Year 2	RU2	4
Undergraduate-Year 3	RU3	4
Undergraduate-Year 4	RU4	4
Total		57

Instrument

The instrument used for data collection in this study was a test that included mental models and external representation patterns developed by Kaharu and Mansyur (2021) consisted of 30 items. In some test items, the respondents were asked to give short answers. In other parts of the test, respondents were asked to describe the state of objects in the water. The test item is dominant in the suspending context. The floating and sinking contexts were provided to determine the initial assumption that the possible patterns of suspending are related to the representation patterns of the two contexts. The test was through a development procedure and shows that the test items have content and face validity in the very good category and Cohen's Kappa reliability (κ) of 0.715 (sig. $p = 0.000$) in the high category (Kaharu & Mansyur, 2021).

Analyzing of Data

The order of data analysis was based on the focus of the study, namely the aspect of the external representation pattern. The data analysis adapted some of the phenomenographic stages (Walsh et al., 2007), which begin with the identification process by checking the respondents' answers. A description pattern was obtained from the process of meaning extraction. The results of pattern identification were integrated by grouping the types of images presented or explanations of the images. Furthermore, the description category was prepared based on the characteristics of the answers and the grouping of respondents based on the category.

For ensuring the reliability of the data analysis, categories that describe variations in perception and description were taken from respondents' answer sheets by focusing on meanings. These initial categories were then retested and compared by different research members, until a set of categories was obtained which was considered to have reached saturation and represented all variations of the data.

Results

In the following, the research results based on the salient themes for each context are presented.

Describing the Position of a Floating Object

Two items asked the respondents to describe the possible positions of suspending objects in the water. The first item provides a figure of three round objects, and the second item did not provide a figure, but the respondents can draw freely about the position of suspending objects. The questions and examples of respondents' answers are presented in Figure 1 (translated).


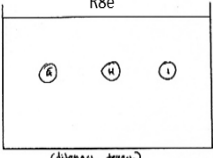
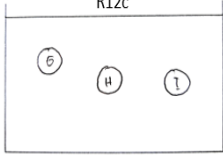
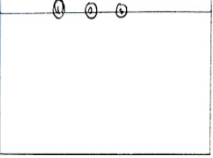
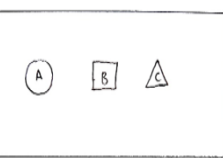
<p>14. The three objects are suspending in the water. Draw the possibilities of the objects' position.</p> 	<p>R8e</p>  <p>(diagonal - tengah)</p> <p>(at the middle)</p>	<p>R12c</p> 
<p>21. Draw the position of the suspending objects in the water (at 3 points).</p>		

Figure 1. Question and Sample of Respondents' Answer (by R8e and R12c) for Depiction of Suspending Objects

Although it appears that there are inconsistencies in some respondents for the two questions, the answers of all respondents can be extracted and grouped into several categories based on their characteristics, as presented in Table 2.

Table 2. Students' Depiction of Suspending Objects at Three Points (Q14, Q21)

Category of Description	Respondents	%
The position varies in the middle of the depth, between the surface and the base	R8g, R9c, R11a*, R12c*, R11f*, R11h, R11i, R11j, R12g*, R12h, RU1b, RU2a*, RU3a, RU3c*, RU3d, RU4c*, RU4d	30
	R8g, R9c, R11h, R11i, R11j, R12h, RU1a*, RU1b, RU3a, RU3b*, RU3d, RU4d	21
The positions are in the middle of the depth	R5a, R5b, R6a, R6b, R8d, R8e*, R8f, R8h*, R9d, R9e, R9f, R9g, R11c, R11e, R11g, R12a, R12b, R12d*, R12e, R12f, R12i, RU1a*, RU1c, RU1d, RU2b, RU2c, RU2d, RU3b*, RU4a, RU4b	53
	R5a, R5b, R6a, R6b, R8b*, R8d, R8f, R9d, R9e, R9f, R9g, R11c, R11e, R11f*, R11g, R12a, R12b, R12c*, R12e, R12f, R12i, RU1c, RU1d, RU2a*, RU2b, RU2c, RU2d, RU4a, RU4b, RU4c*	53
The positions are between the surface and the middle of the depth	R5c, R6c, R8a, R8b*, R9a, R9h, R11b	12
	R5c, R6c, R8a, R8h*, R9a, R9h, R11a*, R11b, R12d*, R12g*	17
The positions are on the surface or near the surface	R8c, R9b, R11d	5
	R8c, R8e*, R9b, R11d, RU3c*	7
Total		98**

Remarks:

*Respondents were not consistent on one pattern for the two questions

**Some respondents did not respond the questions

R5a = Respondent-grade 5 – the **first** person in the same grade

RU2c=Respondent-Undergraduate-year 2- the **third** person in the same grade/year

Table 2 shows that 30% and 21% of respondents drew floating objects with varying positions between the surface and the base. However, the most significant proportion (over 50%) of respondents placed the suspending objects in the middle of the water depth. The data also shows that the respondents described suspending objects as being between the midpoint of the depth and the surface with a reasonably large proportion. There is a position limit for suspending objects in a narrower area, namely between the middle of the depth and the surface. None of the respondents depicted the suspending objects at the base of the vessel. Figure 2 is an interpretation result of the pattern of the depiction of floating objects based on respondents' answers. It is as the vessel's base is a *forbidden area* to be occupied by suspending objects.

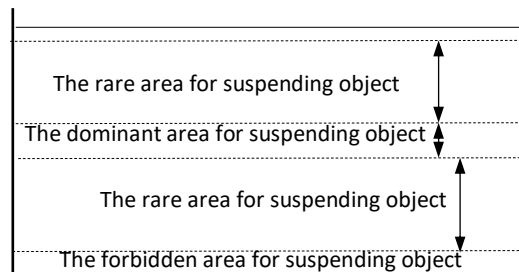


Figure 2. Areas for Depicting the Suspending Objects According to Some Respondents

How was an item asking to explain the state of objects depicted near the surface (item Q17)? Respondents (example in Figure 3) thought that a stable object near a liquid's surface is almost a floating object. The object is considered to have a density less than the density of the liquid. The overall perception of respondents is presented in Table 3.

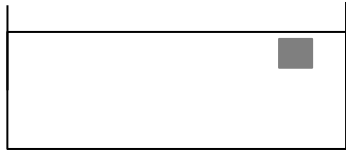
<p>17. An object in the vessel filled with water is in the position as shown. How do you think the object state is? Explain!</p> 	<p>benda tersebut hampir terapung karena massa jenis benda lebih kecil dari air.</p> <p>(The object is almost floating because its density is less than the water's density)</p>
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Figure 3. Question and Sample of Respondent's Answer (R11h) for an Object Near Liquid Surface

Table 3 shows that most respondents thought that objects near the surface are floating objects. Some of the respondents who represented suspending objects with varying positions (from Table 2) were respondents who stated that the position was for a suspending object. In this context, the respondent has a consistent and conceptually precise view that suspending objects can occupy positions near the surface. The overall perception of respondents is presented in Table 3.

Table 3. Respondents' Perception about Objects Depiction Near the Surface

Category of Description	Respondents	%
Objects near the surface: floating objects.	R5a, R6a, R6b, R6c, R8a, R8b, R8f, R8g, R9a, R9c, R9e, R9g, R9h, R11a, R11b, R11c, R11g, R11i, R11j, R12b, R12d, R12e, R12h, R12i, RU1b, RU3a, RU3b, RU3c, RU4b, RU4d	53
Objects near the surface: floating objects whose density is less than the density of water.	R8h, R11h, R12g, RU1a, RU1c, RU1d, RU2a, RU2b, RU2d, RU3d, RU4c	19
Objects near the surface: floating or almost floating or between floating and suspending	R8c, R8d, R8e, R9b, R9d, R9f, R11d, R11e, R11f, R12a, R12c, R12f, RU2c, RU4a	25
	Total	97

Table 3 also shows that a reasonably large proportion of respondents considered objects near the surface to be floating, almost floating objects, or between floating and floating. Some respondents perceived the object as a floating object whose density is less than the density of the water. This answer is a unique form of conception in which the external representation in the verbal form of "suspending object" is inconsistent with the conception of density.

How if the object is represented in a diagram with a position close to the base? Figure 4 shows that there were respondents who thought that object near the vessel's base is sinking object because its density is greater than the density of the water.

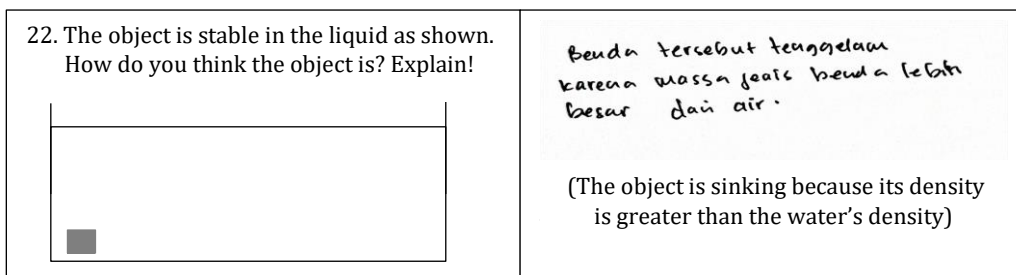


Figure 4. Question and Respondent's Answer (R11h) for Object Near the Base

All respondents' answers were grouped based on their characteristics, and their result is presented in Table 4. The data shows that not all respondents previously thought an object near the surface is suspending, also considered the case of the object near the base as suspending. It illustrates that the scientific model of suspending object has not been fully used consistently in all contexts. A relatively large proportion of respondents perceived object near the base as sinking object or object 'almost' sinking or 'not too' sinking. All levels of respondents embraced this conception. Some respondents thought the object is suspending whose density is greater than the density of water.

Table 4. Respondents' Perception about Object Near the Base

Category of Description	Respondents	%
Object near the base: suspending	R5a, R8a, R8f, R9e, R11a, R11b, R11c, R11i, R11j, RU1b, RU4b	19
Object near the base: suspending object that is almost sinking or suspending object with its density is greater than the density of the water	R8b, R8g, R8h, R9b, R9c, R9h, R11e, R12a, R12b, R12g, R12i, RU1a, RU1c, RU1d, RU2a, RU2b, RU2c, RU3a, RU3c, RU3d, RU4a, RU4c	39
Object near the base: sinking	R6a, R6b, R6c, R8c, R8d, R8e, R9a, R9d, R9f, R9g, R11d, R11f, R11g, R11h, R12c, R12d, R12e, R12f, R12h, RU2d, RU3b, RU4d	39
	Total	97

If the data in Table 4 is compared to Table 3, it appears that the proportion of respondents who considered suspending object near the surface is greater than those near the base. This perception confirms the previous data in Table 3, which shows that suspending object is considered dominantly occupying the boundary between the center of depth and the

surface of the liquid compared to the boundary between the center of depth and the base. In this case, it can be assumed that respondents' view is that the suspending object is localized in a particular area. The area is a dominant upper part of the middle of the depth, and the sinking object occupies a broader area, as shown in Figure 5. However, there is a difference in the proportion of respondents regarding the dominant limit where it depends on the available object position diagrams.

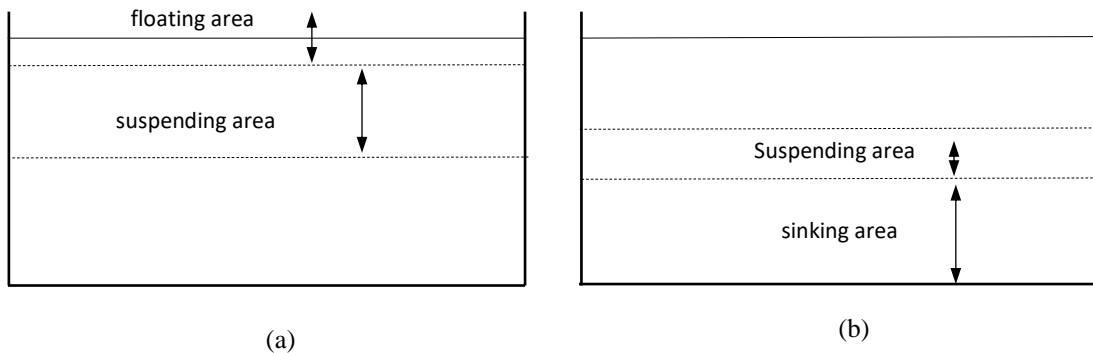


Figure 5. Interpretation of the Effect of the Perception of Some Respondents about the Boundary of the Dominant Area of Floating, Suspending, and Sinking States for the Case of (a) Suspending Objects Near the Surface, (b) Suspending Objects Near the Base

From Figure 5, it can be assumed that some respondents use the meaning or daily language of the word "suspending." The word is associated with the experience that a kite is "suspending" if it is not near the ground. A kite can "suspend" if it is far from the ground. This perception influences their choice and expression when defining near-surface and near-base diagrams. This interpretation is confirmed by the difference in the proportion of respondents.

Representation of Suspending Objects Related to Density

In addition to presenting diagrams representing the state of objects in liquids, objects in various positions are also presented. Two items are specifically designed to explore the concept that relates the position of a floating object and density, namely items Q12 and Q29. Item Q12 (translated) provides verbal information and is accompanied by a diagram of three objects (A, B, and C) in one vessel in different positions. Object A is near the waterline, Object B is in the middle of the depth, and Object C is near the vessel's base. Item Q29 (translated) provides information on three objects (D, E, and F) described through text about the state of objects similar to item Q12. In both items, respondents were asked to briefly explain the density ratio between the three objects and the density of water.

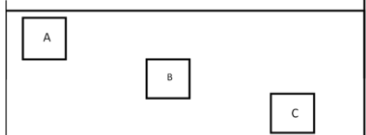
<p>12. Three objects (A, B, and C) are in a vessel filled with water. In a stable state, the three objects are in positions as shown. How do you think the density of objects A, B, and C compared to the density of the water?</p> 	$\rho_A \leq \rho_{air}$ $\rho_B = \rho_{air}$ $\rho_C \leq \rho_{air}$ <p style="text-align: right;">air = water</p>
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Figure 6. Question (Q12) and Sample of Respondent's Answer (R12g)


<p>29. Three objects (D, E, and F) were dropped from different heights into a vessel filled with water. In a stable state, the objects hold in to certain positions. Object D stays in almost appearing in the water surface, Object E is in the middle of the vessel, and Object F is stable near the vessel's base. How do you think the density of objects D, E, and F compared to the density of the water?</p>	 $\rho_D \leq \rho_{air}$ $\rho_E = \rho_{air}$ $\rho_F \geq \rho_{air}$ <p style="text-align: right;">air = water</p>
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Figure 7. Question (Q29) and Sample of Respondent's Answer (R12g)

Respondents were asked to describe the state of these objects in relation to their density. Examples of respondents' answers are presented in Figure 6 and Figure 7. The grouping of all respondents' answers is presented in Table 5.

Table 5. Category of Respondents' Answer for Q12 and Q29

Category of Description	Respondents	%
Suspending objects with $\rho_A = \rho_B = \rho_C = \rho_{\text{water}}$	R9e, R9g*, R9h*, R11c*, R11j, RU1b, RU1d*, RU2c*, RU2d*	16
	R9c*, R9e, R11j, RU1b	7
$\rho_A < \rho_{\text{water}}$, almost floating; $\rho_B = \rho_{\text{water}}$, suspending; $\rho_C > \rho_{\text{water}}$, almost sinking or sinking	R8c, R8f*, R9a*, R9b*, R9c*, R11a, R11b*, R11h*, R12h	16
	R8c, R8d*, R9h*, R11a, R12a*, R12h, RU1d*, RU2d*, RU4b*	
$\rho_A < \rho_B < \rho_C$ or $\rho_A < \rho_{\text{water}}$, $\rho_B = \rho_{\text{water}}$, $\rho_C > \rho_{\text{water}}$	R8a, R8b, R8d*, R8e, R8g, R8h, R9d, R9f, R11d, R11e, R11f, R11g, R11i, R12a*, R12b, R12c, R12d, R12e, R12f, R12g, R12i, RU1a, RU1c, RU2a, RU2b, RU3a, RU3b, RU3c, RU3d, RU4a, RU4b*, RU4c, RU4d	58
	R8a, R8b, R8e, R8f*, R8g, R8h, R9a*, R9b*, R9d, R9f, R9g*. R11b*, R11c*, R11d, R11e, R11f, R11g, R11h*, R11i, R12b, R12c, R12d, R12e, R12f, R12g, R12i, RU1a, RU1c, RU2a, RU2b, RU2c*, RU3a, RU3b, RU3c, RU3d, RU4a, RU4c, RU4d	68
OR $\rho_A \leq \rho_{\text{water}}$, $\rho_B = \rho_{\text{water}}$, $\rho_C \geq \rho_{\text{water}}$		
Total		90

Remark:

* The respondents were inconsistent in one of the depiction patterns in both questions.

The data in Table 5 shows that there is a pattern related to the representation of floating objects. Some respondents thought that a stable object near the surface is a floating object. An object that is stable in the middle of the water is a suspending object. An object that is stable near the base is a sinking object. This data also confirms the previous data on the depiction of suspending objects.

Representation of Objects' State Related to Their Size

Respondents' conception about the effect of the size or volume of objects was explored by some questions arranged that describe the treatment of the objects, namely objects in certain positions (floating, sinking, and suspending) cut into two or three parts the same or different sizes. In this case, the size represents the volume of the object. The large volume is expressed by larger size than other cuts or by a number, while the small size is expressed by smaller size or by a smaller number. Respondents compared large sizes (original objects or large cuts) with small cuts. Then respondents were asked to describe the position of the cuts of objects. There is one item (Q10) related to floating object, and the respondent is asked to choose the right image of the cuts position. One item relates to a picture of a sinking object (Q26) and five pictures of suspending objects in different positions (Q8, Q20, Q25, Q26, Q30). Example of respondent's answer in Q10 is presented in Figure 8. The grouping of respondents' answers is presented in Table 6.

10. Object K floats on a liquid with a position as shown below. Suppose Object K is divided into two parts (M and L) of different sizes. Then the two are put into the same liquid one by one. Which picture shows the correct position of the two cuts?

The diagram shows a rectangular container with a liquid level. Object K is a rectangular block floating at the top. It is divided into two parts, L (smaller) and M (larger). Below are five options (a, b, c, d, e) showing the two parts floating separately. In option (c), part L is fully submerged and part M is partially submerged, which is the correct answer as indicated by the 'X' below it.

Figure 8. Question and Sample of Respondent's Answer (R12c)

Table 6. Description of Respondents' Choices for Depiction of Floating Object Cuts

Category of Description	Respondents	%
The positions of the two cuts are the same as the original object	R8c, R8f, R8g, R8h, R9a, R9b, R9e, R11g, R11j, R12a, R12d, R12e, RU1a, RU1c, RU2b, RU3b, RU3d, RU4a, RU4b, RU4c, RU4d	37
Both cuts right on the surface	R8b, R9h, R11h, R12b, R12f	9
Small cuts of the original object (floating), large cuts at the base (sink)	R5a, R5b, R5c, R6a, R6b, R11c, R11d, R11e	14
Big cuts are lower than small cuts (both float)	R6c, R8a, R8d, R9c, R9f, R9g, R11a, R11b, R11f, R12c, R12g, R12h, R12i, RU1b, RU2c, RU3a	28
Small cuts are lower than the same big cuts as the original object	R8e, R9d, R11i, RU1d, RU2a, RU2d, RU3c	12
Total		100

Table 6 shows that respondents who reviewed the density of objects before and after being divided generally chose the image of the cut position the same as the original object. As many as 63% of respondents chose the place of the floating object cuts different from the original object. The most selected option is a cut with a larger size lower than the original object or a small cut. The data also shows a pattern of representation of cuts of floating objects, namely a 'downward shift' pattern (referred to as a downward shifting pattern) for larger cuts. Respondents seem to focus on the position of the two cuts but ignore the comparison with the original object, which is larger. From this case, it can be stated that there is an internal inconsistency in responding to the phenomenon.

What if a submerged object is cut into two unequal parts? Some respondents (mainly respondents from Table 6) consider the cut size, although some are inconsistent, like R8f (Figure 9). Compare it with the position of R8f in Table 6. The results of the extraction of all respondents' answers are presented in Table 7.

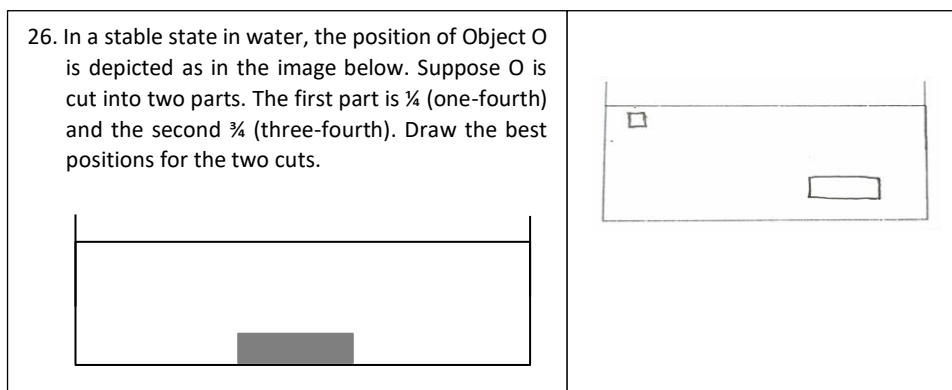


Figure 9. Question and Respondent's Answer (R8f) about Cuts of a Sinking Object

Table 7. Students' Description of Cuts Depiction of a Sinking Object

Category of Description	Respondents	%
Both cuts at the base	R8c, R9e, R11a, R11d, R12a, RU1a, RU1b, RU3a, RU4a, RU4b, RU4d	19
Big cuts at the base, small cuts over big cuts.	R6a, R8a, R8d, R8e, R8f, R9c, R9d, R9f, R9h, R11b, R11f, R11g, R11j, R12c, R12d, R12g, R12i, RU1c, RU1d, RU2a, RU2d, RU3b, RU3c, RU3d, RU4c	44
Big cuts near the base, small cuts on the surface	R5a, R5b, R6b, R8b, R8g, R9a, R9b, R12f, R12h, RU2c	18
Big cuts at the middle, small cuts on the surface/near the surface	R8h, R9g, R11c, R11e, R11h, R11i, R12b, R12e, RU2b	16
Total		97

What is the direction of the shifting of the object being cut is a suspending object? Table 8-Table 11 presents context data for suspending objects cut into two or three parts with different or equal sizes. There are variations in the original object's position, namely near the surface, in the middle, or near the base. In this section, it is expected that respondents will represent cuts of floating objects are placed randomly (without discriminating in size) between the surface and the base. There is an expectation that the cuts are put at the base by supporting an explanation that the cuts are "suspending objects at the base."

Table 7 shows that only 19% of respondents thought that cut size was no effect on the sinking context. In the context, the proportion of respondents who considered the size is greater than in the floating context. In these two contexts, it appears that the respondents consistently dichotomized the two situations. They can distinguish the position of a floating or sinking object. The floating object is on the surface, and the sinking object is at the base. With the consideration of size, this dichotomy has implications for the 'direction' of shifting cuts. In this case, the sinking object tends to 'slide up' (from now on referred to as *upward shifting*). The data also shows variations in the final position of the shift of the cuts. Table 7 shows that the sinking cuts are 'locked' in only two conditions: the large cuts stay at the base (sink) or near the base, and the smaller cuts tend to slide up. The view of size seems to strongly influence the depiction of sinking cuts (Figure 10).

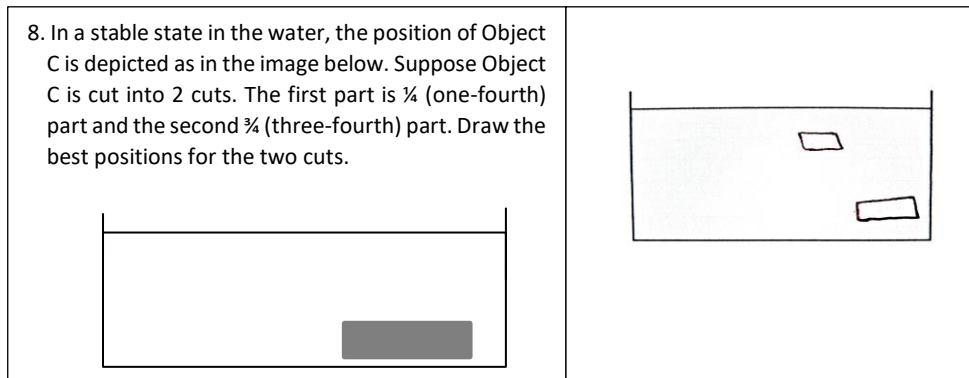


Figure 10. Question and Sample of Respondent's Answer (R5b) about Suspending Object Near the Base: Different Size of the Cuts

Table 8. Students' Description of a Suspending Object Near the Base: Different Size of Cuts

Category of Description	Respondents	%
Both cuts near the base (same as the original object)	R6a, R8b, R8e, R9e, R11a, R11j, R12a, R12d, RU1a, RU3a, RU4a, RU4b, RU4d	23
Big cuts near the base, small cuts over big cuts.	R8a, R8c, R8f, R8g, R9a, R9b, R9d, R9f, R9h, R11b, R11d, R11f, R11h, R11i, R12b, R12c, R12e, R12f, R12g, R12h, RU1b, RU1c, RU2a, RU2b, RU2c, RU3b, RU3c, RU3d, RU4c	51
Big cuts near the base, the same as the original object, small cuts on the surface	R5a, R5b, R6b, R8d, R8h, R9c, R9g, R11c, R11e, R11g, R12i, RU1d, RU2d	23
Total		97

We can only state that the drawing is more scientific than if there were cuts on the surface. Likewise, if a part is placed on the base accompanied by an explanation that a cut is a suspending object, the image can be judged to be more scientific. The data in Table 8 shows a tendency or pattern of representation of cuts of suspending objects near the base following the pattern of sinking objects. The upward shifting pattern is dominant in this context. However, the upward shifting pattern is dominantly limited to the area between the depth center and the vessel's base.

What about the case of the real object suspending near the base (Figure 11) with a uniform cut of the object? Table 9 presents the variation of respondents' answers regarding the position of the cuts for the case of suspending objects near the base, where the size of the cuts is homogeneous.

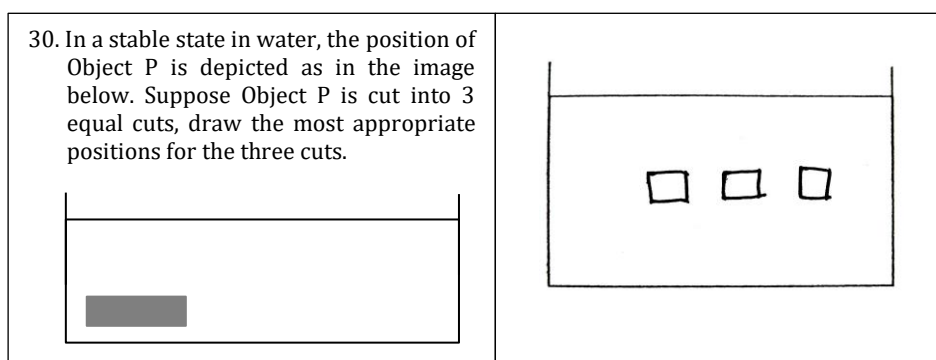


Figure 11. Question and Respondent's Answer (RU3c) for the Case of Suspending Object Near the Base: The Size of the Cuts is the Same

Table 9. Students' Description of a Suspending Object Near the Base: The Same Size of Cuts (Q30)

Category of Description	Respondents	%
The three cuts are the same original object/ near the base	R6a, R8d, R8e, R8f, R9c, R9d, R9e, R11a, R11i, R11j, R12d, R12f, R12g, RU3a, RU3b, RU3d, RU4a, RU4b, RU4c, RU4d	35
The three cuts are at the middle of the depth	R8a, R8c, R8d, R8g, R9g, R9h, R11b, R11c, R11e, R11f, R11g, R11h, R12a, R12b, R12c, R12h, RU1a, RU1b, RU1d, RU2a, RU2b, RU3c	39
The three cuts are on the surface	R5a, R6b, R8b, R8h, R9a, R9b, R9f, R11d, R12i, RU1c, RU2c, RU2d	21
	Total	95

Table 9 shows that the proportion of respondents is quite large (35%) who describe the cut's position as being the same as the original object, which is near the base. The depiction confirms the assumption that there is a rigidity of representation held by the respondents. The position of the cut 'must' follow the position of the original object. A suspending object, including its cuts, can occupy any point between the surface and the base, assuming the object is homogeneous, and water is incompressible. There are differences in the proportion of respondents in Table 8 and Table 9, which show that some respondents distinguished the shift distance between different cut sizes and the same cut sizes.

Almost all respondents thought that the stable object near the base is a sinking object so that the cuts sink. The direction of the shift in the upward shifting pattern with a large, combined proportion (60%) confirms this interpretation. Respondents who presented a cut image in the context of a sinking object (Table 7) and a floating object near the base but with different cut sizes (Table 8) showed data consistency regarding upward shifting. Table 9 also confirms the previous data, showing that some respondents were unaware that a suspending object can occupy any point between the surface and the base.

Next, we consider a suspending object placed in the middle of the depth of the water. What is the position of the cuts? Figure 12 is an example of respondent's answer to the case of a suspending object placed in the middle of the depth. Table 10 presents the distribution of respondents who adhere to a specific pattern with descriptions extracted from the entire data. The data shows that the upward shifting pattern is consistent and dominantly applied in the placement of cuts of suspending object in the middle of the depth. On the other hand, the proportion of respondents is also quite large (44%), which described cuts of suspending object in the middle of the depth following the original object.

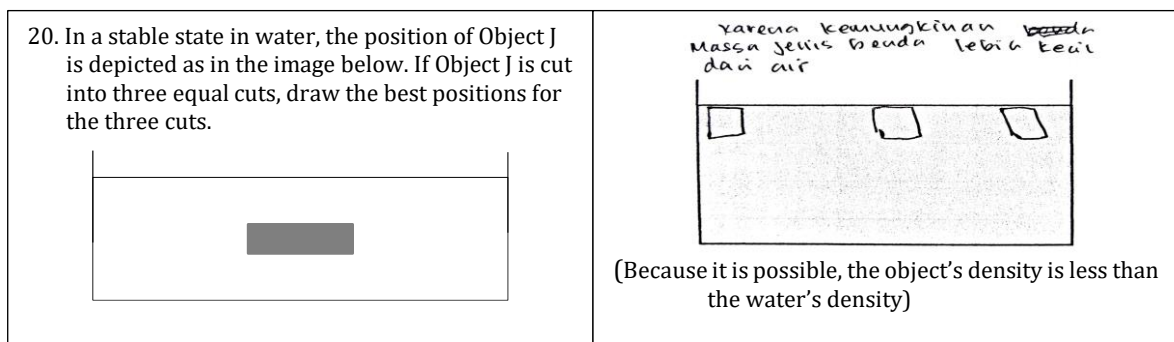


Figure 12. Question and Respondent's Answer (R11h) for the Case of Suspending Object at the Middle of the Depth with the Same Size of Cuts

Table 10. Students' Description of a Suspending Object at the Middle of the Depth: The Same Size of Cuts

Category of Description	Respondents	%
The three cuts are in the random positions between the surface and the base	R6a, R8c	4
The three cuts are at the middle of the depth (as the same original object)	R8b, R8d, R8e, R9c, R9d, R9e, R11a, R11d, R11g, R11j, R12a, R12d, R12f, R12g, RU1a, RU2b, RU2c, RU2d, RU3a, RU3b, RU3c, RU3d, RU4a, RU4b, RU4c,	44
The three cuts are on the surface	R5a, R5b, R6b, R8a, R8f, R8g, R8h, R9a, R9b, R9f, R9g, R9h, R11b, R11c, R11e, R11f, R11h, R11i, R12b, R12c, R12e, R12h, R12i, RU1b, RU1c, RU1d, RU2, RU4d	49
	Total	97

Only two (4%) respondents described the three cuts with varying positions between the water surface and the vessel's base. If one examines the position of the two respondents in the previous contexts, it can be stated that although the

placement of various cuts of object can be considered a scientific model, the two respondents cannot be categorized as adherents of the scientific model. There was an inconsistency of respondents for some contexts of suspending objects. The placement of cuts varies not based on an adequate understanding of the properties of suspending object. If we compare Table 10 with Table 3, there is a striking difference in the proportion of position of a suspending object between the liquid's surface and the vessel base. A more significant proportion of respondents described varying positions for three objects than if the three cuts came from one object. It appears that some respondents have not reviewed the concept of density.

For a suspending object drawn near the surface, the object is cut into three cuts of uniform size. The most significant proportion of respondents described the three cuts as being on the surface of a liquid with the same height (Figure 13). Overall, respondents' answers are grouped as in Table 11.

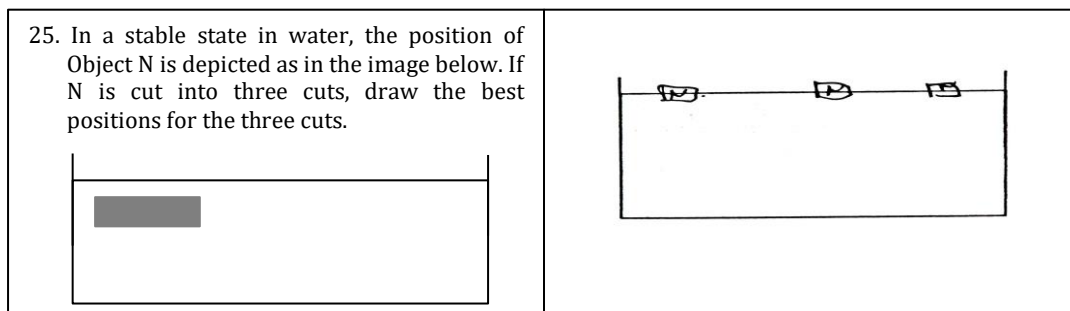


Figure 13. Question and Respondent's Answer (R11b) for the Case of Suspending Object Near the Surface: The Same Size of Cuts

Table 11. Students' Description of a Suspending Object Near the Surface: The Same Size of Cuts (Q25)

Category of description	Respondents	%
Positions of the three cuts are the same original object	R6a, R11a, R11g, R11j, R12d, R12g, RU1a, RU2a, RU2b, RU3b, RU3d, RU4a, RU4b, RU4c, RU4d	26
The three cuts are on the surface	R6b, R8b, R8c, R8f, R8g, R9a, R9b, R9d, R9g, R9h, R11b, R11e, R11f, R11i, R12a, R12c, R12e, R12f, RU1b, RU1c, RU2c, RU2d, RU3a	40
The three cuts are below the surface line (over original object)	R8a, R8d, R8e, R8h, R9c, R9e, R9f, R11c, R11d, R11h, R12b, R12h, R12i, RU1d, RU3c	26
	Total	92

Table 11 shows that 66% of respondents followed an upward shift pattern when describing a suspending object placed in the middle of the depths. The data in Tables 8-Table 11 shows no respondents described the image, which is random, or the same as the original object even at the base and does not depend on the size of the cut. The pattern shows that, in general, respondents understood that suspending objects cannot occupy any point between the surface and the base (the assumption: the water is an incompressible). The dominant pattern is that small sizes tend to be above large sizes. The pattern is relatively no different from the context of sinking objects, even floating objects. The difference in the cuts of the floating object relates only to the '*direction of displacement*.'

Factors Determine Objects' State

The pattern of representation of suspending objects (including floating and sinking in various contexts as previously presented) can be confirmed through items that explore the factors that cause objects to float and sink. Example of respondent's answer for the context of floating object (Q24) is presented in Figure 14. The grouping of answers for all respondents is presented in Table 12.

<p>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!</p> <p>a. Weight of the object b. Gravity c. Mass of the object d. Density of the object e. Density of the liquid f. Volume of the object g. Volume of liquid Give a reason for each of your choice!</p>	<table border="1" style="width: 100%; text-align: center;"> <tr> <td>a</td> <td>b</td> <td>c</td> <td>d</td> <td>e</td> <td>f</td> <td>g</td> <td>h</td> </tr> </table> <p>b. Gaya gravitasi yang besar, sehingga F_A bernilai besar.</p> <p>e. Telur di air garam akan mengapung karena ρ_{air} lebih besar.</p> <p>f. Bola yang lebih besar akan mengapung karena F_A akan bernilai besar.</p> <p>Saya memilih tiga komponen ini, karena merupakan komponen F_{apung}.</p> <p>b. The gravity is great so that F_A is great value.</p> <p>e. Egg in the salt water will float because ρ_{water} is greater.</p> <p>f. A bigger ball will float because F_A is great (F_A = buoyancy).</p> <p>I choose the three components because they are buoyancy's component.</p>	a	b	c	d	e	f	g	h
a	b	c	d	e	f	g	h		

Figure 14. Question and Respondent's Answer (R12i): Factors Determine Object's State

Table 12. Respondents' Conception of Factors Determine Object's State

Category of description	Respondents	%	Pure* or ♦ (%)	‡ (%)
Density of the liquid*	R8a‡, R8d‡, R8e‡, R8f‡, R9a, R9d‡, R9e‡, R9f, R9g, R9h, R11a, R11b‡, R11c‡, R11d, R11f, R11g‡, R11h, R11i, R12a, R12b‡, R12c‡, R12d‡, R12e‡, R12h‡, R12i‡, RU1a‡, RU1b‡, RU1c, RU1d, RU2a, RU2b‡, RU2c‡, RU2d, RU3a, RU3b, RU3d, RU4b, RU4c, RU4d	68	33	35
Density of the object*	R8a‡, R8b‡, R8c, R8d‡, R8e‡, R8f‡, R9a, R9b‡, R9c‡, R9d‡, R9e‡, R9f, R9g, R9h, R11a, R11c‡, R11f, R11g‡, R11h, R11i, R11j‡, R12a, R12b‡, R12c‡, R12d‡, R12e‡, R12f‡, R12g‡, R12h‡, R12i‡, RU1a‡, RU1b‡, RU1c, RU1d, RU2a, RU2b‡, RU2c‡, RU2d, RU3a‡, RU3b, RU3d, RU4b, RU4c, RU4d	77	31	46
Gravity*	R8a‡, R8d, R9d‡, R9e‡, R11b‡, R11f, R11g‡, R12b‡, R12e‡, R12h‡, R12i‡, RU2c‡, RU4a	23	5	18
Mass of the object♦	R5c, R8a‡, R8e‡, R8f‡, R8g, R9b‡, R9c‡, R9d‡, R9e‡, R11b‡, R11g‡, R12b‡, R12c‡, R12d‡, R12e‡, R12h‡, RU1a‡, RU1b‡, RU2b‡, RU2c‡	35	3	32
Weight of the object: as light object floats, while heavy object sinks♦	R5a, R6a, R5b, R6b, R6c, R8a‡, R8b‡, R8f‡, R8h, R9b‡, R9d‡, R11g‡, R12b‡, R12d‡, R12e‡, RU2c‡, RU3c	30	11	19
Volume of the object♦	R8a‡, R8c, R8d‡, R8e‡, R8f‡, R9c‡, R9d‡, R9e‡, R11c‡, R11g‡, R11j‡, R12b‡, R12d‡, R12e‡, R12f‡, R12g‡, R12h‡, R12i‡, RU1a‡, RU1b‡, RU2b‡, RU2c‡	39	2	37
Volume of the liquid♦	R8a‡, R8e‡, R8f‡, R8g, R9b‡, R9c‡, R11g‡, R12b‡, RU2c‡, RU3a‡	18	2	16

Remark:

* = scientific

♦ = non scientific

‡ = respondent combined scientific and non-scientific factors

Table 12 shows majority (68-77%) respondents have considered the density of the liquid and the density of the object as factors that determine the object's state, but at the same time still considered the factors of mass, weight, and volume of the object as well as the volume of the liquid. Only 31-33% of respondents were consistent with the choice in the scientific category. Likewise, 2-11% of respondents were consistent in the non-scientific category. As many as 16-46% were inconsistent in the scientific and non-scientific category. Quite a large proportion of respondents considered the volume of objects even though at the same time also considered the density. Respondents from primary schools were dominantly consistent in the object's weight (as a force variable). Light object floats and heavy object sinks are forms of conception in this group. Unfortunately, this conception is also held by respondents at higher levels. Considering non-

scientific factors such as mass, weight, and volume of objects seems to qualitatively affect the description of objects and perceptions of the image of objects in liquid.

Discussion

The depiction of suspending objects tends to be in the middle of the depths. In essence, it is not always related to the lack of students' conceptual knowledge. Some of them may not try to reason with the formal knowledge gained from the learning process. It can happen because the condition of suspending objects is rare in everyday life. On the other hand, learning activities do not provide adequate space for them to think beyond what is presented by the teacher or the textbook. They involve intuition characterized by a pattern of representation with a simplistic structure in a 'middle way.' The number of respondents categorized into the simplification pattern and made predictions based on intuition was also found by Gette et al. (2018) and Loverude et al. (2003).

The existence of a suspending object representation pattern that seems to have a limited area in the middle of the depth and even the base of the vessel becomes a 'forbidden area' for suspending objects shows the incomplete understanding of the respondents. None of the respondents described suspending objects in the area. Respondents who have described suspending objects with varying positions still have a mindset (Matlin, 2009) that suspending objects cannot occupy the vessel's base. The respondents' attention is only on the word "picture" of "suspending" objects. There is no conceptual effort to take the deep meaning of density as the principle quantity for characterizing objects in liquids. This pattern can also be viewed from the representational flexibility (Deliyianni et al., 2016) that to compose an external representation properly, a representational transformation process is required. In the transformation process, a student needs to involve the fundamental aspects of the phenomena represented by activating the right schema (Slotta et al., 1995).

Representations such as pictures or diagrams of objects are associated with concepts represented through general structural features at the concrete or abstract level (Canlas, 2019). The student needs to extract concepts from textual descriptions using linguistic and semantic knowledge. Linguistic knowledge is used to understand the meaning of words in textual descriptions, while semantic knowledge takes meaning from factual knowledge of phenomena (Solaz-Portolés & Lopez, 2007). Both types of knowledge need to be integrated to produce a conceptually coherent representation. Kohl and Finkelstein (2005) found that student's performance on a particular task sensitively depends on a combination of representations, topics, and their prior knowledge. Although they had a strong opinion of representational skills, that opinion was poorly correlated with performance on the task. Thus, coherence between all aspects is needed to provide optimal performance so that it does not have implications for representational rigidity.

The term representational rigidity introduced in this paper supports the view of the mindset in cognitive psychology (Matlin, 2009). Mindset is a person's mental view that influences the person's approach in dealing with a phenomenon. In this case, the mindset consists of assumptions, methods, or understandings owned by a person or a group that are very firmly embedded. Based on the findings, representational rigidity correlates with the mindset, which is the strength of the respondents' views about a suspending where its position is limited to a specific area.

The absence of a solid understanding of relevant concepts, especially density, creates gaps in their thinking processes and challenges students to build 'bridges' to reconcile inconsistencies in their intuitive conceptions and reasoning (Gette et al., 2018). From the instructional aspect, this conception may be caused by the habit of teachers or textbooks presenting suspending objects in the middle of the depth of the water. A lack of variety in instructional activities, textbooks, and the internet, a presentation can build the concept that suspending object is located at the middle. Such the presentation is not wrong but leaves a problem. Without an adequate explanation, coupled with the lack of facts available in nature or everyday phenomena about suspending, students can develop their conceptual model into a *students' model* that has no scientific value.

Most cross-sectional academic respondents in this study failed to express their understanding of the concepts needed to describe suspending objects. Therefore, for successful learning related to the properties of objects in liquids, a learning design that considers all conditions is needed, it is not only for floating, and sinking. Specific but inappropriate ideas of respondents can be used by teachers in designing their learning to promote deep learning and foster abilities in high-end reasoning (Bao & Koenig, 2019) in an integrative way. Using cognitive conflict (for example) by contrasting ideas and facts from everyday experience can help deal with these failures and make a conceptual change. Conceptual change does not just happen. It requires support from the learning environment and system (Mansyur et al., 2020).

From a review of the data relating to the depiction or conception of images of floating, sinking, or suspending objects and objects that are cut into two or three parts, it appears that there are thinking behaviors that emerge specific representational patterns. There is a dichotomy between floating and sinking in the form of simplification, upward shifting, and others that tend to be influenced by the factors that cause objects to experience floating, sinking, or suspending state. Most of the respondents have considered the density of objects, the density of liquids, and gravity. Unfortunately, at the same time, they considered mass, weight, and volume. There is an inconsistency of the respondent's conception in responding to the phenomenon. Findings of these representational patterns can be related to the knowledge integration (Bao & Fritchman, 2021) and deep conceptual understanding (Shen et al., 2017) and mental model (Furlough & Gillan, 2018) adopted by the respondents. For example, respondents in the upward shifting representation

pattern category were dominant respondents who adhered to the volume-based model. They related the state of matter in a liquid to the volume of the object. The upward shifting pattern is mainly related to the cut size or volume, which is implicitly related to the object's mass. This pattern confirms previous findings that objects that have different masses in the order $m_1 < m_2 < m_3 < m_4 < m_5$ as a five-block problem form a descending line pattern in the order of objects in water (Gette et al., 2018; Loverude et al., 2003). This pattern is one form of student failure to predict the state of objects with different masses.

The items used in this study that asked to describe objects in certain positions were effortless because the respondents only drew point objects or other shapes. However, to obtain these images, the respondents had difficulty. Respondents must integrate their conceptual knowledge about the properties of objects in liquids by relating them to the density of objects and the density of liquids. Lack of conceptual knowledge about these properties impacts the placement of less specific objects. Respondents focus on the position of objects but do not consider the factors that determine the position. Respondents failed in extracting the meaning of density to determine the position. The upward shifting phenomenon for object cuts reflects the respondent's attention to superficial attributes about mass, weight, or visual aspects, namely the volume represented by the object's size.

Conclusion

Based on the previous description, it can be concluded that there is a relatively dominant external representation pattern where there is a simplification of the depiction of suspending objects that tend to be locked in a limited area, namely in the middle of the depth of the liquid. This pattern occurs at all levels. In the context of cutting suspending objects, the cuts are generally represented as having upward shifting. Factors that influence the pattern of representation are the involvement of intuition in conceptualizing the phenomena presented. Another factor is the low consolidation of conceptual knowledge in carrying out formal reasoning obtained through the learning process or the results of curriculum interventions. Some respondents were still influenced by the colloquial meaning of "suspending," so there is confusion in representing or categorizing their representations. In this case, the conceptual aspect of density has not been integrated into the reasoning process in compiling external representations, diagrams, and texts as visual representations, which has implications for the representational rigidity.

Recommendations

It is necessary to provide an adequate portion in the teaching of suspending objects as well as when teaching the concept of floating and sinking. The variation in representing or describing a representation of a suspending object by integrating the concept of density is one way of consolidating their formal knowledge in reasoning about the phenomenon of suspending objects. Further study can be done using online test by involving more respondents with a proportional number at each level so that a transition related to cognitive development due to curriculum interventions can be known.

Limitation

This study involved a disproportionate number of respondents based on levels. As a result, researchers cannot compare the proportions between levels for specific respondents' answers. The researchers also cannot present the location of the maturity transition of the external representation of suspending objects from 5th-grade elementary school students to fourth-year university students as one of the aspects presented in a cross-grade study. Researchers only provided data in the form of a comparison of the percentage of respondents who occupied certain categories related to the representation of suspending objects. Ideally, the percentages are also available in terms of the proportion of each level in that category.

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Authorship Contribution Statement

Mansyur: Study concept and design, acquisition of data, analysis, and interpretation of data, drafting of manuscript, critical revision of manuscript, final approval. Werdhiana: Study concept and design, acquisition of data, analysis, and interpretation of data. Darsikin: Acquisition of data, analysis, and interpretation of data. Kaharu: Acquisition of data, analysis, and interpretation of data, critical revision of manuscript reviewing. Tadeko: Acquisition of data, analysis, and interpretation of data, critical revision of manuscript, editing.

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