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Profile of student critical thinking ability on static fluid concept

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Abstract. Critical thinking ability is an important part of educational goals. It has higher complex processes, such as analyzing, synthesizing and evaluating, drawing conclusion and reflection. This study is aimed to know the critical thinking ability of students in learning static fluids of senior high school students. This research uses the descriptive method which its instruments based on the indicator of critical thinking ability developed according to Ennis. The population of this research is XI\textsuperscript{th} grade science class Public Senior High School, SMA N 1, Sambungmacan, Sragen, Central Java. The static fluid teaching material is delivered using Problem Based Learning Model through class experiment. The results of this study shows that the average student of XI\textsuperscript{th} science class have high critical thinking skills, particularly in the ability of providing simple explanation, build basic skill, and provide advanced explanation, but they do not have high enough in ability of drawing conclusion and strategic and tactical components of critical thinking ability in the study of static fluid teaching material. The average of students critical thinking ability is 72.94, with 27.94\% of students are in a low category and 72.22\% of students in the high category of critical thinking ability.

1. Introduction

The static fluid concepts are mostly involved in daily life activities. By learning the static fluid concepts teaches the student to think, find problems in everyday life and solve them based on relevant theories and concepts. Static fluid teaching material discusses hydrostatic pressures, Pascal law, Archimedes law, and surface tension. Many students have their own opinions about the concept of the object that is immersed inside of the static fluid that will be sinking, fully immersed, or floating. The behavior of these objects is obeyed to Archimedes law and students still have a misunderstanding of Archimedes law due to their daily lives experience. On the other hand, the ability to think critically is close to the understanding of the concept, therefore by understanding the concept appropriately students are expected to be able to think critically and vice versa.

Fluid is collections of molecules arranged by force (cohesion and adhesion) and by the forces acted by the container wall. Liquid and gas objects are classified as fluid. In studying static fluid we do not need to learn new physics principles to explain pressure and a buoyant force acting on floating and
sinking objects [1] since the behavior of floating and sinking objects in static fluid could be explained by using Newton laws [2,3,4,5].

The Archimedes law states that if an object is immersed in the static fluid then it will experience a drag (upward) force equal to the volume of fluid that is removed. Therefore if an object is immersed in the static fluid, its weight will be reduced by the amount of the weight of the liquid that is removed, the object’s weight in the static fluid is called as apparent weight. This statement is illustrated in Figure 1. The object that has mass m kg, volume V m$^3$, height h, area cross section A and density $\rho_0$ is hung on a spring balance and immersed into the static fluid that has density $\rho_1$, schematically shown in Figure 1. Figure 1 shows the derivation of Archimedes law for the apparent weight of the object that is fully immersed by applying the Newton first law where w is the object weight measured in the air.

\[
\begin{align*}
F_1 &= P_0A = \rho_0gh_0A, \\
F_2 &= PA = \rho_1gh_1A
\end{align*}
\]

The drag force $F_d = F_2 - F_1 = \rho_1gh_1A - \rho_0gh_0A$.

By using Newton first law from figure 1 we have

\[
T + F_2 = w + F_1
\]

then $T = w - F_1 = w - \rho_1gh_1A$

The apparent weight $w_a$ is equal to rope tension $T$ measured by spring balanced is $w_a = T$

Figure 1. Illustration of forces acted on the object hung on the spring balanced scale that is fully immersed in the static fluid

From the observation this law is suitable for floating and fully immersed objects, as shown in Figure 1, for the sink object, on the other hand, the object that falls on the bottom of container will experience normal force acted by the container’s bottom, so there is no more drag force from water to the lower part of the block as shown in Figure 2. Figure 2 shows the illustration of forces that acted on an object that sinks in the static fluid in the container. The object that sinks has a size of the object in Figure 1 but the density is different given by $\rho_b$.

\[
\begin{align*}
F_1 &= \rho_bgh_1A, \\
F_2 &= PA
\end{align*}
\]

$T$ is the measure apparent weight $w_a$ measured by the spring balance and $N$ is normal forces acted by the bottom of the container, therefore the apparent weight of the object is $T = w_a = w - (N - F_1)$.

Figure 2. Illustration of forces acted on the sink objects that are hung on spring balance scale

From the discussion it is expected that the apparent object weight that sinks are smaller than the apparent object weight that is fully immersed, that is $N > \rho_bgh_1A$. Therefore it could be said that the Archimedes law is not suitable for the immersed object in the static fluid that is a sink. One of teaching or learning model that should be used to deliver this concept appropriately is problem-based learning model through guided inquiry method.

Critical thinking has been one of the most important human skills in twentieth-century [6]. The thinking process not only reflects to conclude and synthesizes information but also allows individuals
to make reasonable thinking in the classroom as well as in everyday life [7]. Students need critical thinking in academic life. All academic tasks require their critical thinking. Finally, however, teachers want them are not only to practice these skills in the classroom but also apply the skills into the real world in their everyday life[8]. Holma [9] suggests that it is not enough for students to have critical thinking skills, but they also need to use these skills effectively. To build the student’s critical thinking ability, teachers should often ask some cognitive questions that promote a student to evaluate and synthesis of facts and concepts learned [10].

In psychology view, critical thinking is considered as a skill and focuses on the process of thinking. Some psychologists refer to Bloom's classification to define critical thinking and focus on critical thinking among Bloom's thinking ability [11].

Ennis [6] mentions the critical thinking indicators are as follows: 1) Provide a simple explanation which includes: focus on questions, analyze arguments, and clarify questions; 2) Build basic skills assessing: the credibility of an information source, making observations and judging observation reports; 3) Sum up, including making and assessing deductions, making a decision; 4) Provide further explanations, including defining terms and judging definitions, identifying assumptions; 5) Strategies and tactics, including: deciding actions and interacting with others.

Teachers as educators can use various learning methods to promote the critical thinking. Although educators judge a student who thinks critically about concepts, passion or disposition for critical thinking, and this is not always owned by all students. Many schools expect their students to think critically [13]. Teaching problem-based learning is an effective learning model that encourages students through reinforcing their critical thinking to gain skills to solve problems.

Problem-based learning is a learning model that involves student to solve a problem through the stages of a scientific model [14]. So that student can learn the knowledge related to the problem and also have the skills to solve. The results of a study show that students who have difficulty explaining floating, fully immersed and sinking objects and can not identify the force that actions those objects.

2. Research Method

The sample of this research is 11th graders of science class from SMA N 1 Sambungmacan Sragen Central Java Indonesia. The research that has been conducted in January to June 2017 using the descriptive method. The instrument is developed based on the indicator of critical thinking ability of the static fluid that includes the ability of student in: (1) Analyzing the relationship between the depth of fluid and pressure on a fluid, (2) Analyzing the relation of drag force with the depth of the fluid and the area of object, (3) Applying the Archimedes law for floating, fully immersed, and sinking objects phenomenon, (4) Explaining the meaning of surface tension correctly. The instrument of the study has been validated by the expert which consists of 10 essay questions with a rubric score between 0 to 100. The static fluid teaching material is delivered to the students using Problem Based Learning Model through class experiment.

3. Results and Discussion

In this study, students answer sheets of problems that have been developed based on critical thinking ability indicators are analyzed. The indicators of critical thinking ability consist of: (1) provides a simple explanation, (2) build basic skills, (3) Conclude, (4) Provides the further explanation, (5) Set strategies and tactics. Each indicator of student critical thinking ability is represented by the student understanding of static fluid which is provided in the form of student answer sheets.

The results of research that have been conducted shows that, for all indicators of student critical thinking ability, 73.3% of students achieve above the average value of critical thinking ability which is 72.94 with the variance of (16.77), the highest score achieved by the student is 84.54 and the lowest score is 47.73. The student critical thinking ability is classified into two groups, low and high category of each critical thinking ability indicator, shown in Table 1. From Table 1 can be seen that most students have achieved the critical thinking ability in the level of provides a simple explanation, build
basic skills and advanced explanation. These results indicate that students' critical thinking ability is good except for Setting strategies and tactics.

Table 1: The average, low, and high score of student for each indicator of critical thinking ability

| No | Critical thinking ability          | Low   | High   | Average score |
|----|----------------------------------|-------|--------|---------------|
| 1  | Provide simple explanation       | 26.7% | 73.3%  | 76.7          |
| 2  | Build basic skills               | 16.7% | 83.3%  | 75.4          |
| 3  | Conclude                         | 33%   | 66.7%  | 68.5          |
| 4  | Advanced explanation             | 20%   | 80%    | 74.3          |
| 5  | Setting strategies and tactics   | 43.3% | 57.7%  | 69.8          |

The following illustration is an example of student answer sheets both for incorrect and correct answers for any indicator of student critical thinking ability. Figure 3(a) shows the incorrect student answer and Figure 3(b) for the correct student answer for the first indicator of critical thinking ability which provides a simple explanation of hydrostatic pressure concept.

When you swim in 1 m depth, your ears do not feel pain, but when you swim at 5 m depth why your ears feel pain? Explain the force that acts on the ear drum when you swim in 1 m depth and 5 m depth if the area or ear drum is about 1 cm²!

The deeper is the swim, the more pain is felt since the fluid density is greater for the deeper fluid then the pressure is greater in the deeper fluid.

\[ P_h = \rho gh = 1000 \times 10 \times 5 = 50000 \text{ N/m}^2 \]

\[ P_h = \rho gh = 1000 \times 10 \times 1 = 10000 \text{ N/m}^2 \]

3. Pada saat kita menelung di kedalaman 1 m telinga kita tidak merasakan sakit, tapi mengapa saat kita menelung ke dalam kolam yang dalamnya 5 m telinga kita merasakan sakit? Jelaskan berdasarkan gaya yang bekerja pada gendang telinga saat menelung di kedalaman 1 m dan 5 m dengan perkenaan luas daerah dari gendang telinga sekitar 1 cm² adalah ...

\[ A = 1 \text{ cm}^2 = 10^{-4} \text{ m}^2 \]

Semakin dalam gendang telinga semakin besar tekanan yang merasakan lebih sakit.

When you swim in 1 m depth, your ears do not feel pain, but when you swim at 5 m depth why your ears feel pain? Explain the force that acts on the ear drum when you swim in 1 m depth and 5 m depth if the area of each ear drum is about 1 cm²!

**Student correct answer**

\[ \text{For} = 10 \text{ m/s}^2 \text{ dan } \rho = 1000 \text{ kg/m}^3, \ A = 10^{-4} \text{ m}^2 \]
When swim in deeper fluid the ears feel more pain since the hydrostatic pressure $P$ is greater at the deeper fluid, the hydrostatic pressure is given by $P = \rho gh$ and the hydrostatic force is $F = PA$.

At 1m depth, the hydrostatic pressure and force are
$P_1 = \rho gh_1 = 1000 \cdot 10 \cdot 1 = 10000 \text{ N/m}^2$, so $F_1 = P_1 A = 10000 \cdot 1 \cdot 10^{-4} = 1 \text{ Newton}$

At 5m depth, the hydrostatic pressure and force are
$P_2 = \rho gh_2 = 1000 \cdot 10 \cdot 5 = 50000 \text{ N/m}^2$, so $F_2 = P_2 A = 50000 \cdot 1 \cdot 10^{-4} = 5 \text{ Newton}$

This results show that the hydrostatic pressure and force that act at the ear drums are greater so that it feels more pain.

Figure 3b: Example of correct student answer about the concept of hydrostatic pressure

Based on the sample of students’ answers presented in Figure 3 (a) and (b) can be seen that there are students that do not understand correctly about a simple explanation of hydrostatic pressure and they still do not focus on the understanding of the water density which has to be homogenous for the entire swimming pool. In this case, students are expected to understand the relation between force and pressure at any object, particularly force and pressure that resulted by the static fluid. But most students have been able to solve the problem properly according to the concept that the hydrostatic pressure increases by the increase of the fluid depth by using the assumption that whole fluid is homogenous [15]. Even for the incorrect answer, the student has known the definition or concept of the hydrostatic pressure. As shown in Table 1 the percentage of students that be able to provide a simple explanation is more than 70 %.

Figure 4 shows the example of student answer for the fourth indicator of student critical thinking ability which is the level of advanced explanation where the student is asked to analyze the concept of floating, fully immersed, and sinking according to Archimedes law.

Draw the forces acting on a floating, fully immersed, and sinking objects in a static fluid, and explain it according to Archimedes law!

The weight of the object that sinks to the vessel’s bottom is heavier than the object’s weight that is fully immersed and object’s weight that is fully immersed is heavier than the weight of the floating object. The drag force of an object that fully immersed equals to its weight.

Figure 4. Incorrect student answer for concepts of floating, fully immersed, and sinking objects

Based on the student’s answer sheet shown in Figure 4 can be seen that student still could not understand the concept of floating, fully immersed, and sinking objects if an object is immersed in the static fluid based on the free body diagram of each phenomenon and relation of all forces to Archimedes law. A student can not identify factors that influence why the object is floating, fully immersed, or sinking explicitly. It is seen from the answer sheet that student is still not able to identify all forces that act on the object and then draw it. In addition, they can also not be able to identify the quantities that related with Archimedes law. But Table 1 shows that most students have achieved the advanced explanation indicator (80%), this may be explained that Archimedes law and its application is difficult to part for students in static fluid teaching material.

Figures 5(a) and (b) show the same object that is weighed when it is fully immersed and when it is sinking by using the spring balance scale. The critical thinking ability indicator that will be measured using this problem is the ability of the student to draw a conclusion which is the third indicator of critical thinking ability.
A block that has volume of \(132 \text{ cm}^3\) and mass of 0.305 kg is weighed in the air using spring balance, then the block is fully immersed into the water while it is weighed using the same spring balance and its scale showing 1.75 N. Moreover, then the block is lower until it is sitting at the vessel’s bottom (perfectly sink) and the spring balance scale showing 0.35 N. Find:

a. The Archimedes force that acts to the block when it is fully immersed in the water!

b. The normal force that acts to the block by the bottom of the vessel when the object is sink!

**Solution**

a. \(F_A = (m/V)gV = 3.05 \text{ N}\)

b. \(N = W - T = W - W_{\text{true}} = 3.05 \text{ N} - 0.35 \text{ N} = 2.75 \text{ N}\)

Figure 5 (a). Examples of incorrect student’s answer on the fully immersed and sinking objects

A block that has volume of \(132 \text{ cm}^3\) and mass of 0.305 kg is weighed in the air using spring balance, then the block is fully immersed into the water while it is weighed using the same spring balance and its scale showing 1.75 N. Moreover, then the block is lower until it is sitting at the vessel’s bottom (perfectly sink) and the spring balance scale showing 0.35 N. Find:

a. The Archimedes force that acts to the block when it is fully immersed in the water!

b. The normal force that acts to the block by the bottom of the vessel when the object is sink!
sink!

**Solution**

a. \[ T = \text{w}_{\text{true}} = \text{w}_{\text{apparent}} = 1.75N \]
the drag force \[ F_A = \rho_{\text{water}} g V_{\text{obj}} = 1000 \times 10 \times 1.32 \times 10^{-4} = 1.32N \]

b. \[ T = \text{w}_{\text{true}} = \text{w}_{\text{apparent}} = 0.35N \]
\[ W_{\text{udara}} = w_{\text{true}} + N, \ N = 2.75N \]

**Figure 5 (b). Examples of incorrect student’s answer on the fully immersed and sinking objects**

The data put into the problem shown in Figure 5 is the real data recorded from the class experiment. It is seen from the data that the apparent weight of the block that calculated from the experimental data using Archimedes law which is equal to \( w_{\text{app}} = 3.05N - 1.32N = 1.73N \) and measured data using the spring balanced scale which is equal to \( T = w_{\text{app}} = 1.75N \). This shows that these two data are in agreement fairly, that means Archimedes law is applicable in that class experiment.

Figure 5 (a) shows the incorrect student answer both parts a) and b) problems. To understand the application of Archimedes law or Newton first law for the fully immersed object, students have to understand how to draw all forces that act on the object as shown in Figure 1. In addition, students have also to understand that the apparent weight can be measured using spring balance scale. From Figure 1 students have to be able to express the relationships of the hydrostatic forces, downward and upward, tension force by spring, and gravitational force by earth on the object. By applying the first Newton law \[ 15 \] students are able to determine the apparent weight from experimental data. Therefore the apparent can be measured directly using spring balance or can be calculated using the first Newton law with the experiment data so that students can compare the apparent weight from direct measurement and from the calculation. From this discussion can be concluded that to understand the application of Archimedes law for immersed object based on experiment data that related with daily life is very complex that need very high critical thinking skill, not just drawing conclusion ability, therefore there are still many students that experience misunderstanding of application of Archimedes law in this problem.

For problem (b) by using an analogy where the normal force acted on the sink object by the vessel’s bottom is similar to the hydrostatic force \( F_2 \) (upward direction) in the problem (a). The critical thinking skill used to understand for the sink object is more complex compare to fully immersed object since the Archimedes law is not applicable, but the Newton first law is still applicable, however, both of two student’s answers, Figure 5 (a) and (b) are still incorrect. This condition indicates that the student still does not understand the application of Newton law in floating and sinking objects. The experiment data shows that the normal force is much greater than the hydrostatic force \( F_2 \).

From the example of student answer sheets show that in a static fluid, the most part that hardly understood is phenomena of floating, fully immersed and sinking objects that its behavior explained using Archimedes law except for sinking object. Furthermore, the application of Archimedes law will be easily understood if the student involved in laboratory activity since students can compare the calculated result obtained from the calculated data using mathematical equation derived theoretically from the first Newton law and measured data from an experiment using spring balance scale. Loverude states that the standard of learning hydrostatics in many sciences class can not predict and explain the behavior of sinking and floating objects on simple objects\[1\]. The sinking, fully immersed, and floating phenomena are learnt better by using the laboratory with supported by student worksheets and handout and therefore students’ critical thinking skills will be improved, particularly for conclusion ability and strategic and tactic ability which is not good enough compare with the other four critical thinking ability indicators, shown in Table 1. As revealed by Newton, PG \[ 16 \] that in solving the problem related to the critical thinking ability, the student must first know the concept underlying a problem, then visualize the problem schematically to see the relation of the variables or basic concepts, and solve the mathematical equation.
4. Conclusions
The profile of students’ critical thinking ability of 11th-grade students in SMA N Sambung Macan, Sragen, Central Java, were mostly high. Students’ critical thinking ability is measured through the ability of student in solving static fluid problems, particularly on hydrostatic forces and Archimedes law concepts that learned by problem-based learning model via experiment. For indicators of critical thinking ability that have been set up according to Ennis, it was shown that the critical thinking ability of student are: 27.94% for the low category, 72.22% of high category which means that the critical thinking ability score is above of the average score, where the average score is 72.94. Most of the students have achieved critical thinking ability at the level of providing a simple explanation, build basic skill, and advanced explanation, but they are not high enough for the level in drawing a conclusion and strategic and tactic.

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