Student and Teacher Understanding of Buoyancy

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Abstract. We report on the findings of a research study on student and teacher understanding of concepts relating to floating, sinking and density. The findings are based on 156 Grade 7 students and 46 in-service science teachers, mainly from the secondary level. We present and discuss preliminary quantitative and qualitative data for this study obtained using self-developed and adapted pre-tests from the *Properties of Matter* module found in *Physics by Inquiry*. Our analysis will highlight difficulties that were prevalent among students, as well as those common for both teachers and students. The implications for development of instructional materials for students and professional development of teachers on this topic will also be discussed.

Keywords: buoyancy, sinking, floating, density, physics by inquiry, alternative conceptions
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INTRODUCTION

Children develop their ideas about how things work based on their everyday experience with phenomena in the natural world [1]. These ideas or *alternative conceptions* (ACs) are generally resistant to change and are often incompatible with currently accepted scientific knowledge. These ACs are also known to influence and interfere with formal learning in school. Developing students' ability to explain major phenomena and to apply principles and models based on scientifically justifiable conceptions of the natural world remains an important challenge for educators.

Sinking and floating is an everyday phenomenon that students are commonly exposed to. Previous studies of student understanding on buoyancy reveal several ACs [1-4]. For example, students at the primary grades often predict if an object sinks or floats based solely on its weight, without considering its volume. Many students also focus on specific features of objects, such as air trapped inside or holes in the object, and make predictions based on these features.

This paper aims to identify and determine the prevalence of conceptual and reasoning difficulties faced by students and teachers relating to the sinking and floating behavior (SFB) of objects. This is part of an on-going research to develop and validate effective inquiry-based classroom materials and instruction for secondary-grade students in Singapore classrooms.

METHODOLOGY

The participants for this study were Grade 7 students and in-service teachers, mainly from the secondary level. The students can be described as having above average academic ability, based on their Primary School Leaving Examination results taken at the end of primary education in Grade 6. The teachers were mostly either physics or engineering majors, with a median teaching experience of about 5 years.

We have analyzed a sample size of 156 students and 46 in-service teachers. All data for this study were collected by analysis of responses to free-response written questions constructed by a team of university professors, research associates and curriculum specialists as well as those adapted from the *Properties of Matter* module found in *Physics by Inquiry* [5].

The pre-tests served to set the stage for learning and to elicit preliminary thinking about the topic. Previously, students would have learned about different materials' ability to sink or float in water, and how to measure mass and volume using appropriate apparatus. The pre-tests were administered to students over three weeks within their school science curriculum before formal instruction in the topic of *density*. For the teachers, the pre-tests were administered as part of their in-service workshops on inquiry-based instruction in physics.

TASKS AND RESULTS

There were a total of 6 pre-test questions (**Q1-Q6**), of which only the first 4 were administered to students. In our analysis, we report on ACs that had been observed in at least 10% of the sample.

Analysis Of Student Difficulties

Inability to Distinguish Mass, Volume and Density

Q1 showed two same sized cubic blocks made from different materials, completely immersed in cylinders that were initially filled with water to the same level. **Q1a** asked to make a comparison of the displaced water levels where the brass block was suspended at a higher level than the aluminum block but still completely immersed. **Q1b** asked to make a comparison of the final displaced water levels when both the blocks were released and allowed to sink to the bottom of the cylinders.

45% of students were not able to distinguish the concepts of mass, volume and density (**AC1**). Of these, two thirds (30%) stated the level of displaced liquid depended on the mass of the immersed object: "*brass is heavier than aluminum hence the brass block puts more pressure on the water so the water level rises up more*". Statements such as: "*both the aluminum block and the brass block have equal mass and take up the same amount of space*" and "*the brass block has a higher density, which results in a higher water level in cylinder 2*" indicate that students did not distinguish the concepts of *mass*, *volume* and *density*. Even when students used the term "volume", they could be thinking of "mass": "*the volume of the brass block is bigger than the aluminum block thus the water level should be higher*".

Displaced Liquid Level Depends on Immersion Depth

Based on **Q1b**, 20% of students alluded that the level of displaced liquid depended on the depth at which the object was immersed. Of these, half (10%) thought that level of the displaced liquid was affected by the depth at which the block was immersed (**AC2**): "*the water level in cylinder 1 rise a little but the water level in cylinder 2 is at the top of the cylinder as it had overflowed*". The other half (10%) overlooked the given information and thought that the brass block was not completely immersed, even though the question clearly stated that it was completely covered by water: "*the brass block is not completely lowered into the water in cylinder 2, so it will occupy less space and hence, the water level will be lower*".

Heavy Object Sinks and Light Object Floats

Q2a showed a large object (sinker) immersed in a tank of water, and asked to make a prediction of the SFB of each of 1000 pieces that were broken off from the object. **Q2b** showed a small block A (floater) floating on water, and asked to make a prediction of the SFB of another block B, made from the same material, that was 1000 times larger in size.

30% of students specifically stated that the SFB of an object depended on its size or mass (**AC3**). If its mass was small enough, it would float and if its mass was big enough, it would sink. A further 20% were able to provide a superficial explanation for the SFB in terms of *relative density*. But upon further probing in the question, wrote that smaller pieces from an initially large sinker may float, while a big object made from small floaters of the same material may sink (**AC4**). They reasoned that the density of the object changed with the size of the object: "*the density of every 1000 smaller pieces decrease when it was broken and smaller pieces has less density hence may be able to float. If the size of Block B is 1000 times the size of Block A, its density is also 1000 times the density of Block A hence can't float*".

SFB is Affected by the Amount of Liquid

Q3a showed a large object (sinker) immersed in a tank of water, and asked to make a prediction of its SFB when water was removed or added to the tank. **Q3b** showed a small object (floater) in a tank of water, and asked to make a prediction of its SFB when water was removed from the tank. **Q3c** asked specifically if the density of water changed when the volume of water was changed.

20% of students thought that the amount of water in the tank affected the SFB of the object (**AC5**). Of these, half (10%) thought that adding more water might cause a sinker to float or that removing more water might cause a floater to sink: "*I am not sure if A can float with an increase in the volume of water, it depends on the amount of water added…(The floater) might sink if too much water was removed*".

Most students with **AC5** reasoned that the density of water changed with the volume of water. A typical line of reasoning was: "*as the amount of water decreases, so does the density of the water; lesser volume of water means lesser density*". A smaller number of students reasoned that: "*density is mass divided by volume so when the volume changes* (increases), *the density changes (decreases)*", without considering the corresponding increase in mass when a greater volume of water was used.

SFB Depends Only on the Property of the Object

Q4a showed a floater in water and asked to make a prediction of its SFB when it was placed in oil. **Q4b** showed a sinker in water and asked to make a prediction of its SFB when it was placed in oil. **Q4c** asked specifically if an object's SFB depended on the liquid it was placed in.

TABLE 1. Percentage of correct responses to the questions by students (N = 156) and teachers (N = 46).

Question	Correct Responses to the Questions	Student	Teacher
Q1	The level of displaced liquid depends on the volume of the object (sinker) and the height at which the object is placed in the liquid does not matter as long as it is completely immersed in the liquid.	50%	100%
Q2	An object's SFB depends on the relative density of the material and the liquid. If its density is smaller than the liquid, it will float regardless of its size. Conversely, if its density is larger than the liquid, it will sink regardless of its size.	35%	90%
Q3	The SFB of a sinker (or floater) is not affected by the amount or volume of liquid it is immersed in; changing the volume of liquid in a tank does not alter its density.	50%	95%
Q4	Able to make correct deductions about an object's SFB in a second liquid, given the object's SFB in the first liquid and the relative densities of the two liquids.	50%	95%
Q5	The volume of liquid displaced for each identical object in different liquids is the same as long as the objects (sinkers) are completely immersed. For identical floating objects, the volume of liquid displaced is less for the denser liquid.	Not tested	50%
Q6	Correct positions drawn for other blocks for the *five-block problem* (see Ref. 6).	Not tested	55%

10% of students thought the SFB of an object depended only on the property of the object (as was the case for **AC3**) and the liquid it was immersed in does not matter (**AC6**): *"whether the beaker is filled with water or oil does not matter, what matters is the material of the object. Therefore, if it floats, it floats on both oil and water"*. Evidently, these students did not understand that SFB is the result of an interaction between the object and the liquid.

Objects Float "Better" in liquids with Lower Density

Responses to **Q4** revealed that 15% of students thought that objects were more likely to float in liquids with lower density (**AC7**): *"as water is denser than oil and the object that floats in water can surely float in oil too."* A possible cause for such thinking could be the confusion with the behaviour of a hot-air balloon, which produces a greater net upward force when the density of the air inside the balloon decreases.

Reasoning Difficulties in the Context of Two Liquids

Responses to **Q4** indicate students experience both reasoning and conceptual difficulties. 25% of students were not able to make correct deductions about an object's SFB in a second liquid, given the object's SFB in the first liquid and the relative densities of the two liquids (**AC8**). For example, 15% of students stated that the numerical values of the densities of the object and liquids must be explicitly given before any conclusions can be made. They did not realize that if the object sank in water, it would also sink in oil, since oil was less dense than water. The other 10% of students simply stated the object floated or sank in oil based on sweeping assumptions made about its density relative to oil: "*the object is about the same density as oil, but it could possibly be denser, so it sinks in oil.*"

Analysis Of Teacher Difficulties

Based on **Q1-4**, there was no evidence of significant occurrence of **AC1-6** among teachers but 15% of teachers also displayed **AC8**. Further teacher difficulties were revealed by **Q5-6** below.

Q5a showed two identical beakers filled to the same level, one with water and one with oil, and asked to make a comparison on the rise of the oil level and water level when identical *sinkers* were immersed in the liquids. **Q5b** asked to make a comparison on the rise of the oil level and water level when identical *floaters* were placed in the liquids instead.

For **Q5,** 15% of teachers thought that the volume displaced by a floater was more when immersed in oil compared to water "*as it floated higher in oil"*. This is similar to the idea that objects floated "better" in liquids with lower density (**AC7**) that was observed among students. In addition, 25% of teachers thought that the volume of liquid displaced was the same for identical objects placed in different liquids, regardless of whether the objects were sinking or floating in the liquids (**AC9**).

Q6 was the *five-block problem* which showed five cubical bocks of equal mass but different size ($V_1 < V_2 < V_3 < V_4 < V_5$). The final positions of block 1 (sunk to bottom) and block 4 (barely floating) were also shown. The question asked to make a prediction of the final positions of the other blocks in water. 40% of teachers gave a "descending line" response [6], in which the blocks appeared at successively lower levels in the water (**AC10**).

DISCUSSION AND CONCLUSION

The comparison of percentage of correct responses to each question by students and teachers is given in Table 1. It can be seen that students tend to struggle

TABLE 2. Alternative conceptions and reasoning difficulties of students (N = 156) and teachers (N = 46).

AC	Description of Alternative Conceptions and Reasoning Difficulties	Students	Teachers
AC1	Not able to distinguish the concepts of mass, volume and density. E.g. students think that the level of displaced liquid depends on the mass of the immersed object; the greater the mass of the object, the greater the level of displaced liquid.	45%	-
AC2	The level of liquid displaced depends on the depth the object is immersed in the liquid. E.g. the greater the depth of immersion, the greater the level of displaced liquid.	10%	-
AC3	The SFB of an object depends on the size or mass of the object. E.g. smaller sized objects tend to float and bigger sized objects tend to sink.	30%	-
AC4	Smaller pieces from an original large sinker may float while a bigger object made from an original small floater made from the same material may sink.	20%	5%
AC5	The SFB of an object is affected by the amount of water. E.g. more water added, sinker will float or more water removed floater will sink.	20%	5%
AC6	The SFB of an object depends only on the property of the object; the liquid it is immersed in does not matter.	10%	-
AC7	Objects float "better" in liquids with lower density. E.g. an object that floats in water will also float in oil since oil is less dense than water. The volume displaced by a floater is less when immersed in oil compared to water as it floats higher in oil.	15%	15%
AC8	Inability to make reasoned deductions about object's SFB in the context of two liquids. E.g. requiring density values to be explicitly given or making sweeping assumptions.	25%	15%
AC9	The volume of liquid displaced is the same for identical objects immersed in different liquids, regardless of whether the objects are sinking or floating in the liquids.	Not tested	25%
AC10	"Descending line" response for the *five-block problem* (see Ref. 6).	Not tested	40%

with more elementary concepts like mass and volume, as well as applying the concept of *relative density*. There may be a tendency for rote application of rules or formulas, with little conceptual understanding. The fact that students think that density of objects can change with size and that of liquids can change with amount or volume highlights the need to emphasize the concept of density as a *characteristic property* of substances during formal instruction.

As seen from Table 2, teachers, unlike students, do not have difficulty with applying the concept of *relative density* in the context of an object placed in a liquid. The difficulty sets in only when making comparisons about the SFB in the context of multiple objects and liquids.

We observe that about half of the teachers were able to extend the idea of *relative density* to correctly obtain their answer for **Q5b**: "*the object will 'sink' more compared to in water, so the oil level will rise more*". For **Q6**, a typical response to why teachers drew block 5 as they did was: "*it (block 5) has less density than block 4, therefore it must float higher*". However, 25% and 40% of teachers were not able to correctly apply the idea of *relative density* to **Q5** and **Q6** respectively. We think that strengthening the understanding of SFB as fundamentally being due to the effect of forces would help to better reflect the connection between SFB and *relative density* in the context of multiple objects and liquids. Only 15% of teachers explained their answers in terms of upthrust and balanced forces.

We have identified conceptual and reasoning difficulties relating to sinking, floating and density that were prevalent among students, as well as those common for both teachers and students. There is a need to design curricula materials that explicitly address the identified ACs [7-8], as well as to provide more opportunities for teachers to learn deeply the curricula materials in a manner that is consistent with how students learn to better facilitate inquiry-based instruction.

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