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Author(s)	D. Wong, C. C. Lim, S. K. Munirah and S. K. Foong
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PBI1@SCHOOL: ON SECONDARY ONE STUDENTS' UNDERSTANDING OF VOLUME AND DENSITY

D. Wong

Natural Sciences and Science Education, National Institute of Education,

Nanyang Technological University, Singapore

C.C. Lim

Centre for Research in Pedagogy & Practice, National Institute of Education,

Nanyang Technological University, Singapore

S. K. Munirah

Centre for Research in Pedagogy & Practice, National Institute of Education,

Nanyang Technological University, Singapore

S. K. Foong

Natural Sciences and Science Education, National Institute of Education,

Current Address: Department of Physics, Nagoya University, Nagoya 464-8602, Japan

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Abstract

In this paper, we focus on students' understanding of the concepts relating to buoyancy: namely, (a) the level of displaced liquid as being dependent on the volume of the object that is submerged in it, and (b) density as a characteristic property of a material which is unaffected by its size. The study used a pretest-posttest control group design. The students were secondary one (grade 7) students. Due to limitation of time, the data in this paper were derived from analysing two classes (N = 72) out of six in the experimental group which experienced the PbI1@School curriculum, and two classes (N=80) out of five in the control group which were taught using the traditional approach. We used two pretests to probe students' preconceptions of the two concepts (a) and (b) stated above. The common preconceptions identified from students' answers in the pretests include: the idea that mass and/or weight of the object and the depth at which an already completely immersed object is placed below the surface of the liquid affect the level of displaced liquid. Another common preconception is the idea that the mass/weight of the object determines its buoyancy (i.e. whether it will sink or float). From the reasoning seen in their responses, it was clear that many students, prior to instruction, were not able to distinguish between the concepts of mass, weight, volume and density. Results from our analysis showed the effectiveness of the adapted inquiry-based materials and instruction in developing student conceptual understanding. A good understanding of the common student preconceptions and how instruction can be designed and facilitated to help students resolve their preconceptions to better learn the concepts would be beneficial to physics teachers in secondary school.

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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 preconceptions are generally resistant to change and are often incompatible with currently accepted scientific knowledge. They 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 revealed several preconceptions [1-4]. For example, students at the primary grades often predict that an object sinks or floats solely based 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 the prevalent conceptual and reasoning difficulties faced by students relating to the topic of buoyancy as well as to determine the impact of inquiry-based instruction in delivering the topic in school.

Method

The participants of our study are secondary one (grade 7) students from a Singapore school. They are of above average ability, with a typical Primary School Leaving Examination T-score of about 240. This study followed a quasi-experimental pretest-posttest control group design. Data was collected from a total of 152 students: 72 students (two classes) in the experimental group; and 80 students (two classes) in the control group. The samples were chosen conveniently based on the classes assigned by the school to the teachers. The experimental group and control group were each taught by a different teacher.

The research instruments used for this study were pretests and posttests. The focus of the pretest questions was on qualitative understanding of concepts as demonstrated by students' ability to explain the reasoning for their answers and did not require application of formulae and mathematical calculations. All data for this study were obtained by analysis of students' responses to written questions constructed by the research team as well as those adapted from the *Properties of Matter* module found in *Physics by Inquiry* [5].

The pretests served to set the stage for learning and to elicit students' preconceptions about the topic. Previously, at the primary level, students would have learned about different materials' behaviour in water, whether they would sink or float, and how to measure mass and volume using appropriate apparatus. The pretests were administered to students during curriculum time prior to formal instruction.

Rubrics and Coding Scheme

The rubrics formulated for the pretest and posttest were based on the completeness of conceptual understanding as determined by the reasoning that the students wrote to support their specific answers to multiple choice questions rather than just looking at the simple ‘correct’ answers which the students chose from a list of distracters. Responses which displayed justification and reasoning that were based on scientific concepts and ideas were awarded a maximum score of 2. Incomplete responses which displayed partial conceptual understanding and reasoning were awarded a score of 1 and those with wrong reasoning, no reasoning or not attempted were given the minimum score of 0. The coding scheme for students’ responses is summarised in Table 1.

TABLE 1. Coding scheme for students’ responses.

Coding Criteria	**Score**
Correct answers displaying complete understanding and reasoning	2
Correct answers displaying partial understanding and reasoning	1
Incorrect reasoning or no reasoning	0

Task and Results

Pretest Analysis of Student Difficulties

Inability to Distinguish Mass, Volume and Density

Pretest 1 showed two same-sized cylinders filled with water to the same level. It was stated in the question that two same-sized cubic blocks made from different materials were lowered into two separate measuring cylinders to completely immerse them in water (see Fig. 1) and that the brass block was heavier than aluminium block. Students were asked to mark out the level of displaced water for the cylinder with the heavier brass block suspended at a higher level than the aluminium block. Students were finally 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.

From students' responses, about half of the students were not able to distinguish the concepts of mass (and/or weight), volume and density. For example, many thought that the level of displaced liquid depended on the mass (and/or weight) of the immersed object: "*brass is heavier than aluminium hence the brass block puts more pressure on the water so the water level rises up more*". Statements such as: "*both the aluminium 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 aluminium block thus the water level should be higher*". In addition, there were students who gave the correct response on the resulting water level but based on wrong reasoning such as

"The water level in cylinder 2 will be of the same level as cylinder 1 because even though the brass is heavier than the aluminium block, it is immersed at a higher level in the water.

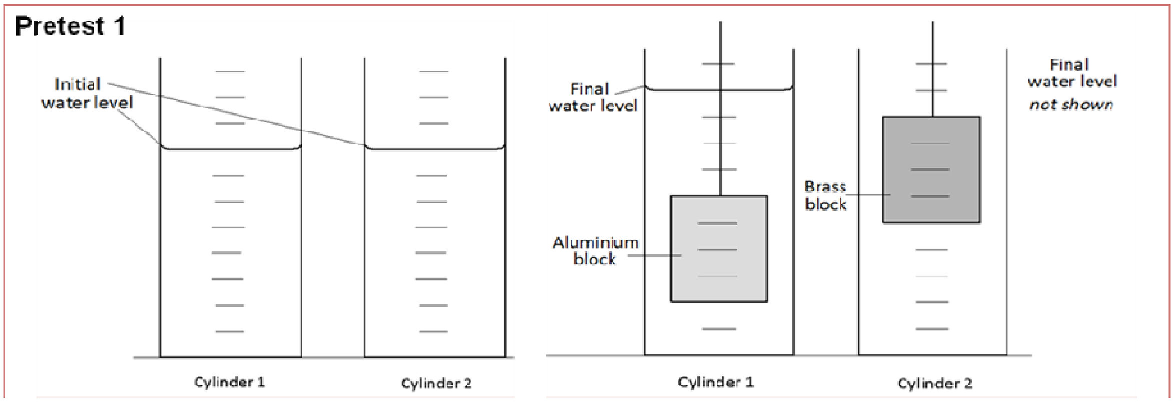

Fig. 1. Diagram used in **Pretest 1.** Respondents were asked to make a comparison of: (a) the displaced water levels where the brass block was suspended at a higher level than the aluminum block but still completely immersed. (b) the final displaced water levels when both the blocks were released and allowed to sink to the bottom of the cylinders.

Student responses from Pretest 1 also revealed that some students thought that the depth at which an already completely immersed object was placed affected the level of displaced liquid. For example, when asked to compare the final displaced water levels when both the blocks were released and allowed to sink to the bottom of the cylinders, sample responses included: "*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*", "*water will flow out of the cylinder when they are released, and the brass block is dropped from a higher place, so more water will overflow*" and "*the weight of the blocks does not affect the volume but the brass block is higher up so it pushes less water up*". Admittedly, some students could have 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*", "*the weight of the blocks does not affect the volume but the brass block is higher up so it pushes less water up*" and "*the brass block is not completely put into the water, so the mass of it is not completely added to the water level*".

Heavy Object Sinks and Light Object Floats

Pretest 2 probed the understanding of what actually determines the buoyancy or sinking and floating behaviour (SFB) of an object through the SFB of: (a) a smaller piece of object broken off from a large sinker? (b) a large block made from the same material as that of a small floater (see Fig. 2).

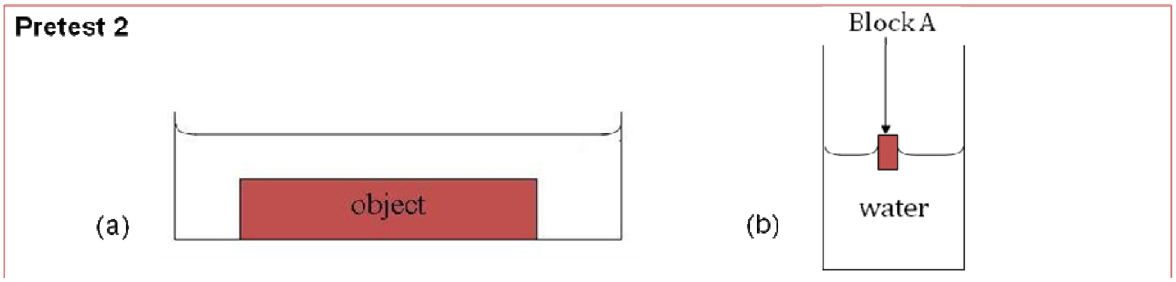

Fig. 2. Diagram used in **Pretest 2** showing: (a) a large object (sinker) immersed in a tank of water, and respondents asked to make a prediction of the SFB of each of 1000 pieces that were broken off from the object. (b) a small block A (floater) floating on water, and respondents asked to make a prediction of the SFB of another block B, made from the same material, that was 1000 times larger in size.

About 30% of students specifically stated that the buoyancy of an object depended on its size or mass: “*If its mass was small enough, it would float and if its mass was big enough, it would sink*”, and “*those which are lighter will float and those which are heavier will sink*”. A further 20% of students gave a superficial explanation for buoyancy using the term *relative density* which they might not understand. Thus, upon further probing in the question, stated that smaller pieces from an initially large sinker may float, while a big object made from small floaters of the same material may sink. Some 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”*.

Descriptive Statistics for Pretests

The basic descriptive statistics for the pretest scores for concept 1 and concept 2 is shown in Table 2 and Table 3 respectively.

TABLE 2. Students’ pre-test scores for concept 1 (height): how height at which an object that is completely immersed affects the level of liquid displaced.

Class	**Mean**	**SE**	**SD**
C1 (N = 39)	1.21	.07	.98
C2 (N = 41)	0.95	.07	1.00
E1 (N = 35)	0.69	.15	.90
E2 (N = 37)	0.86	.16	.98

TABLE 3. Students' pretest scores for concept 2 (sinker): what is the buoyancy of smaller pieces of objects broken off from an original large sinker.

Class	Mean	SE	SD
C1 (N = 39)	0.69	.14	.86
C2 (N = 41)	1.07	.16	1.01
E1 (N = 35)	0.66	.15	.87
E2 (N = 37)	0.49	.14	.84

An independent-samples t-test showed that the pretest scores for concept 1 for the two control classes C1 and C2 were statistically insignificant, t(80)=1.15, p=.25, and that for the two experimental classes E1 and E2 pre-test scores were also statistically insignificant, t(72)=0.81, p=.42. This was also the case for concept 2, where C1 and C2 pre-test scores were statistically insignificant, t(80)=1.81, p=.07 and E1 and E2 pre-test scores were also statistically insignificant,_t(72)=0.85, p=.40. For subsequent analyses, we combined the two control classes to one group and two experimental classes into one group.

Pretest-Posttest Analysis

Table 4 gives a summary of the percentage of students who obtained correct answers for the various concepts for the pretest and posttest. As one would expect, the percentage of correct answers increased for all concepts for both control and experimental groups after instruction. From question 2 of the pretest, an interesting observation is that students found concept 2 (sinker) relatively more difficult compared to concept 2 (floater), since more students got the latter correct (32% compared to 39% correct) This means that while students have not acquired the understanding that density is a characteristic of a material prior to instruction, they are more likely to accept that a large object made from small floaters would still float but less inclined to accept the fact that a smaller piece taken from a large sinker would still sink.

TABLE 4. A comparison of students’ understanding of the various concepts for the pretest and posttest.

Question	Concept	Pretest %Correct			Posttetest %Correct		
		Expt (N=72)	Ctrl (N=80)	**All (N=152)**	Expt (N=72)	Ctrl (N=80)	**All (N=152)**
1. What affects the level of liquid displaced?	1(height)	35%	53%	**44%**	67%	56%	**61%**
	1(mass)	42%	50%	**43%**	89%*	80%*	**85%***
2. What affects the buoyancy of an object?	2(sinker)	24%	40%	**32%**	54%	44%	**49%**
	2(floater)	33%	45%	**39%**			

**posttest question was set as a multiple-choice question*

For the posttest, there was no corresponding question for concept 2(floater) and concept 1(mass) was set as a multiple choice question without the need for students to give any reasoning as there is a limit on the time and number of questions we could set for the test.

As can be seen from Table 4, for concept 1(height), the control group performed better (53%) than the experimental group students (35%) in the pre-test but the experimental group performed better (67%) than the control group students (56%) in the post-test.

We next focus on comparing the performance of concept 1(height) and concept 2(sinker) for the two groups (i.e. control versus experimental).

Analysis of Student Performance for Concept 1(Height)

Table 5 shows the basic statistics of the pretest and posttest scores for concept 1(height) for the control and experimental groups.

TABLE 5. Concept 1(height) - how height at which an object is completely immersed affects the level of liquid displaced.

Group	**Test**	**Mean**	**SE**	**SD**
C (N = 80)	Pretest	1.08	0.11	0.99
	Posttest	1.34	0.09	0.83
E (N = 72)	Pretest	0.78	0.11	0.94
	Posttest	1.54	0.08	0.71

Hake’s normalized gain [6]

$$\langle g \rangle = \frac{\langle \text{posttest score} \rangle - \langle \text{pretest score} \rangle}{< \text{maximum possible posttest score} > - \langle \text{pretest score} \rangle}$$

gives the mean normalised gain for the experimental and control group as $<g>_{expt} = 0.63$ and $<g>_{ctrl} = 0.28$, thus the gain achieved by the experimental group is 2.3 times higher than the control group. A further breakdown by gain (posttest score – pretest score) reveals that more experimental group students gained by 1 and 2 marks for the question on concept 1(height) compared to the control group students, as shown in Figure 3. possible posttest score

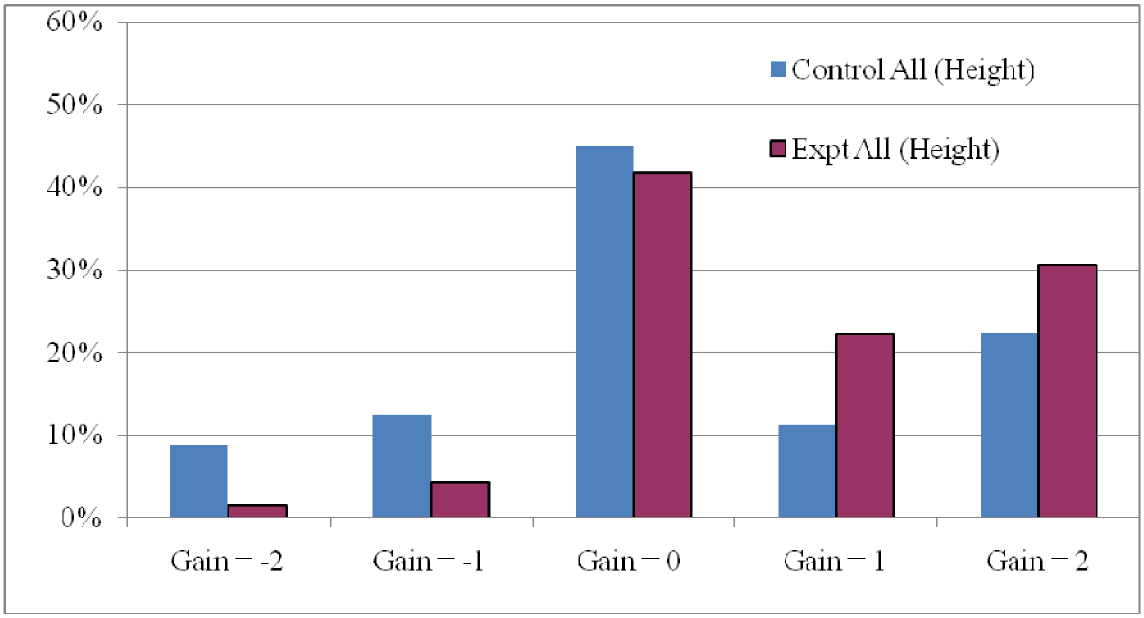

Fig. 3. Comparison of gain (posttest score - pretest score) for the control and experimental group for concept 1(height).

Analysis of Student Performance for Concept 2(Sinker)

Table 5 shows the basic statistics of the pretest and posttest scores for concept 2(sinker) for the control and experimental groups.

TABLE 5. Concept 2(sinker) – the buoyancy of smaller pieces of objects broken off from an original large sinker.

Group	**Test**	**Mean**	**SE**	**SD**
C (N = 80)	Pretest	0.89	0.11	0.95
	Posttest	1.04	0.10	0.92
E (N = 72)	Pretest	0.57	0.10	0.85
	Posttest	1.17	0.11	0.95

Using the formulae for Hake's gain, we obtained the group-average normalised gain for the experimental group as $\langle g\rangle_{expt} = 0.42$ and that for the control group as $\langle g\rangle_{ctrl} = 0.13$. A further breakdown by gain (posttest score – pretest score) is shown in Figure 4.

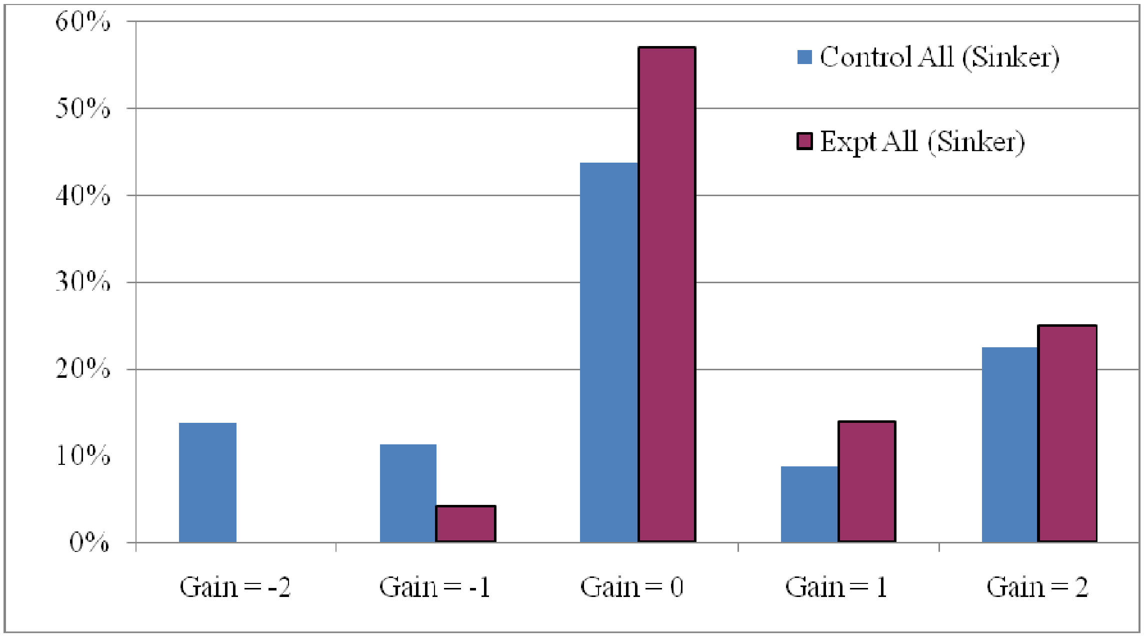

Fig. 4. Comparison of gain (posttest score - pretest score) for the control and experimental group for concept 2(sinker).

As can be seen from the gain figures in Figure 4 and the normalized gain for both groups of students, the experimental group outperformed the control group students for concept 2(sinker).

Conclusion

This study has identified some of the common student preconceptions relating to buoyancy and it has also shown the effectiveness of inquiry-based materials and instruction in developing students' scientific understanding of concepts. Teachers need to be familiar and confident with facilitating the use of instructional materials that systematically builds up student's investigative and reasoning abilities leading to student's functional understanding of concepts and phenomena, and in the process they also address the identified student preconceptions.

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