hands on

Diagrams: Useful tools for investigating a student’s understanding of buoyancy

by Christine Creagh

Sometimes it is difficult to decide whether a student has a true understanding of a physics concept or whether they are very good at rote learning key words and phrases. Sometimes, when you are marking exams, you feel you have to give the student full marks because everything is there, even though it is not quite ‘right’. This is where a diagram can be very useful in probing the student’s understanding.

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The following question was given in an end of semester examination for an introductory (first year) university physics unit.

You have an irregular-shaped object. How can you use buoyancy to help you work out its density? Remember to draw a diagram.

In this situation it could be expected that the students would be trying their hardest to show their knowledge of the subject. An examination is possibly as controlled an environment as can be contrived: the students work on their own, they all have the same task, in the same conditions and all are allowed the same resources. In this examination the students were allowed a calculator (scientific or graphics) and two sides of an A4 sheet of paper notes / formulae / diagrams / worked examples. The memory of the calculators were not cleared before the examination as, from past experience, it does not seem to make any difference, in general, to the final marks. Past examination scripts are therefore a useful resource when looking for material to determine how students demonstrate their understanding of physics using diagrams.

The prerequisite level of understanding for the unit is a pass in Year 12 tertiary entrance examination Physics and Calculus or equivalent. The students should therefore have met the concepts of force, density and volume before engaging in this unit and they should be able to do the algebra required to answer the above question. The content had been covered in lectures and they might even have had a related assignment question. Drawing diagrams was expected as part of answering the assignment questions, so asking for a diagram in the examination answer would not have been unusual.

Box 1 shows the type of answer found in text books and given in lectures.

Box 1 Textbook Explanation: Standard diagram for finding the density of an object using buoyancy

Answer

To find the density of the object it is necessary to first find its mass and its volume.

What we know:

- The volume of the crown is the same as the volume of the water it displaces.
  \[ V_s = V_{\text{water}} \]
- The weight of the water displaced is equivalent to the buoyancy (B) which is the difference between the two tensions illustrated above.
  \[ F_s = m_s g = B = T_s - T_2 \]
- The mass of water displaced is equivalent to the weight of the water divided by the acceleration due to gravity
  \[ m_s = F_s / g = (T_s - T_2) / g \]
- The volume of water displaced is equivalent to the mass of the water divided by density of the water displaced.
  \[ V_s = m_s / \rho_s = (T_s - T_2) / g \rho_s \]
- As we said at the beginning this is equal to the volume of the crown.
  \[ V_s = V_c = m_c / \rho_c = (T_s - T_2) / g \rho_c \]
- The weight of the crown is equivalent to \( T_s \), i.e. the crown is weighed in air.
  \[ F_s = T_s \]
- So the mass of the crown is the weight divided by the acceleration due to gravity
  \[ m_c = F_s / g = T_s / g \]
- Which gives us the density of the crown as
  \[ \rho_c = m_c / V_c = (T_s / g) / [(T_s - T_2) / g \rho_s] = T_s / (T_s - T_2) \rho_s \]
This is a long-winded and difficult-to-follow explanation. It also assumes, even though it does not state it, that $T_1 > T_2 > 0$, i.e. that the object is more dense than water but that its density is not so great that the buoyancy of water is insignificant.

If a student gave this 'text book' answer could you be sure they understood the concept, or had they just copied the example from their sheet of notes? Perhaps the latter, as the magnitude of $T_1$ as indicated by the length of the vector, plus the buoyancy, does not equal the initial tension. Possibly the student has not grasped the idea that the length of a vector indicates its magnitude. Is the discrepancy just due to a little carelessness on the student's part? ... So, full marks?

The concept is simply stated in the first sentence in Box 1 'To find the density of the object it is first necessary to find its mass and its volume'. If students concentrated on learning the above solution, rather than the concept, they would have difficulty in answering the examination question if they had not had the foresight to include it on their A4 sheet.

The following are the answers given by four students, each demonstrating a different level of understanding of the concept of buoyancy.

**Box 2 Student 1: Simple force diagram for buoyancy**

*Answer*

The object can be weighed out of the water and then submerged and weighed again. The difference in weight is the force exerted on the object by buoyancy. The volume of water displaced by the object determined from $x - x'$ is the volume of the irregular object. This volume divided by its weight gives the density in kg/m$^3$. Assume the water container is of uniform known dimensions. Assume the mass sinks. If the mass floats force can be applied in the direction of gravity until it just sinks to determine buoyant force.

This student has a 'text book' type diagram which does show buoyancy acts in the opposite direction to weight and complements the first two sentences which do not make this point explicitly. The rest of the answer is also correct but they have not demonstrated that they understand that the buoyant force is equal and opposite to the weight of the water displaced. Perhaps this is why they have not been able to turn the concept around to show how buoyancy could be used to determine the mass of the object. This answer indicates the first stages of learning, where all the parts are memorised but have not yet been brought together into a conceptual whole. As the student has not been able to use buoyancy to help them determine the mass of the object it is not possible to give them many marks for this answer.

**Box 3 Student 2: A slightly less 'scientific' diagram**

*Answer*

The mass of the volume of liquid displaced by the object is equal to the mass of the object (when it floats). This is because the buoyant force is equal to mg. When the object is completely submerged the increase in volume is equal to the volume of the object. By using the formula density = mass / volume the density of the object can be worked out.

At first glance, this diagram appears to be less 'scientific' than the previous example. The object is indeed irregular, as though this is an important factor in considering this problem, and the vector for the buoyant force is pushing up on the bottom, instead of acting through the centre of mass. So, on its own the diagram might lead one to assume the student does not have a very good understanding of the concept. On reading the text it is discovered that the student does understand the concept of buoyancy and can apply it in a limited range of situations, where the object is less dense than the liquid it is immersed in. Note that the two force arrows in the diagram are the same length, indicating balanced forces as described in the text 'the buoyant force is equal to mg'. Another indication that the student sees these forces as balanced is that in the diagram the object is floating. This student is therefore a little further along in obtaining a full understanding of the concept.

**Box 4 Student 3: Diagram showing hands-on experience**

*Answer*

Firstly a fluid must be found in which the object floats. For this explanation it will be assumed that the object floats in water. A vessel must first be filled with water up to the level of the overflow.

The object can then be gently placed in the vessel to float and the amount of water displaced will be equal to the amount that leaves the system via the overflow.

Density can be calculated as follows

- The mass of the water leaving the overflow in the first displacement is equal to the mass of the object.
- The total volume of water from both displacements is equal to the volume of the object.
- The mass and volume of the object are now known and density can be calculated as follows

\[
\text{Density} = \frac{\text{mass}}{\text{volume}}
\]
Here is a useful set of diagrams for showing how buoyancy can be used to determine the density of an irregularly-shaped object, as long as the density of the object is less than that of the fluid it is immersed in. The student understands the concept of buoyancy, as demonstrated by the middle illustration, where the weight of the object is equivalent to the weight of the water it displaces when it is floating. The student also demonstrates an understanding of the scientific method and experimental error by the use of the phrase ‘a thin object that will cause negligible displacement of the water’ when talking about submerging the object. It is possible this set of diagrams has its origins in a hands-on activity performed at high school, as this apparatus was not used or described in this unit. This student, like the last one, has grasped the concept but still approaches it from a methodological angle. They cannot ‘play’ with the concept yet.

**Box 5 Student 4: The ability to ‘play’ with a concept**

![Diagrams](image)

Obtain density by the amount of water it displaces by weight then by volume. By knowing both weight of water displaced (giving weight of mass) and volume of water displaced (giving volume of mass) density \( \rho_w \) is obtained.

\[
\rho_w = \frac{\text{mass of displaced water}}{\text{volume of displaced water}}
\]

White and Gunstones, in their chapter on drawings (White and Gunstone 1992), demonstrate how ‘Drawings reveal to teacher and student the ideas held by the student’. In this paper the diagrams were created for the purposes of assessment and the examiner used them as a tool to gather information about student understanding. It is possible that they could also be used to facilitate student learning. By presenting a group of students with these sorts of diagrams and asking them to rank them on their usefulness in answering the question, a group discussion could be instigated that touches on all the subtleties of the concept under investigation. The importance of speech in learning was highlighted by Vygotsky around 1930 (Vygotsky 1987). Using real student diagrams, as opposed to ‘textbook diagrams’, also adds relevance, making it easier for students to relate to them.

**Diagrams and understanding**

I have attempted to show that diagrams can play a role in helping us to determine the level of understanding a student has about the concept of buoyancy. A better way to probe a student’s understanding is of course during an individual interview but to do this for every student would take a great deal of time. Asking students to draw diagrams in written assignments and examinations is therefore a time-effective way of obtaining extra information about the students understanding.

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**References**


**About the author:**

Dr Christine Creagh has been lecturing in first-year Physics at Murdoch University for four years and says that in that time the cohort has changed from a handful of highly motivated physics students to a large group of mostly non-physics students. She is always looking for ways to get them talking about Physics and working with the concepts. This is where she noticed that those students who could put together a useful diagram seemed to have a better grasp of the concepts.

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