Freely rising bottle of water also demonstrates weightlessness

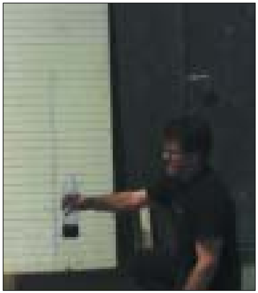

Figure 1. *Bottle at rest; water jets are flowing out of the bottle.*

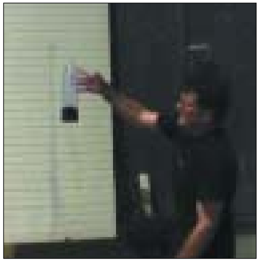

Figure 2a. *When the bottle starts moving up freely, the water stops flowing out.*

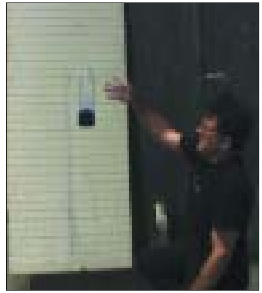

Figure 2b. *40 ms after the moment shown in figure 2a.*

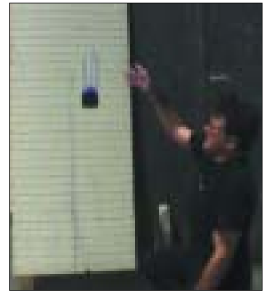

Figure 2c. *80 ms after the moment shown in figure 2a.*

A popular physics demonstration shows students that jets of water flowing from a container will stop if it is allowed to fall freely. The demonstration can be found in physics teachers' course books [1], physics textbooks [2–4], on the Web [5] and also in educational journals [6].

What is less well known is that students' explanations of this phenomenon do not match the scientific explanation that the bodies, while being in a free-falling reference frame, are weightless. Some students conceptualize it in a kinematical way: the water and bottle move down in the same way, so the

Box 1. What will happen to the jets after the bottle is launched up?

Suppose that a person holds the bottle with the two water jets flowing out (figure 1) and, instead of letting it fall down, launches it upwards.

When the bottle leaves the person's hand and moves up alone, the water jets will: (a) stop flowing out, (b) flow out faster, (c) flow out slower or (d) flow out as before.

State, as precisely as you can, the reasoning behind the answer you select.

water isn't able to flow out. Others are likely to attribute the flow stopping to the 'air'.

We describe a lesser known version of this demonstration, which is quite surprising for students. It is best to plan it as a Predict–Observe–Explain (POE) activity [7]. This kind of activity is very effective at showing the way students think about a specific modification of a studied physical situation. A possible format of this POE activity is given in Box 1.

Although students have seen that the water jets stop flowing when the bottle is in free fall, the majority of them are thoroughly convinced that the correct answer is (b): the water jets will flow out faster.

Their reasoning is often an analogical elaboration of a kinaesthetic experience: 'When a person is in an elevator that is moving up from rest, she or he feels heavier. Consequently, when "heavier", the water should flow out faster.'

This is evidence that students rarely pick an answer without doing their best to justify their choice with readily available knowledge and/or experience. In addition, in this case a sensory experience is 'logically' combined with a well known alternative concept of motion in which 'heavier bodies fall faster'.

Being convinced that the water should flow out faster, students are very surprised to observe that it stops flowing out at the instant when the bottle starts freely moving upwards (figure 2).

This is the time to discuss with the students possible explanations for this surprising outcome of the experiment. Some students will revive their kinematical explanation, which is then preferred to the 'heavier water' argument. They will say that water and bottle, when launched upwards, move in the same way, and water isn't able to flow out.

To help them get on the right track, it might be necessary to consider a 'trivial' problem: why does water flow out from a hole drilled in the side of a stationary bottle? It takes longer than expected to reach the answer; the cause isn't the air pressing on the water's surface from above (balanced by air pressing on the hole from the side), but the water's hydrostatic pressure (due to its weight). When this is grasped by the students, they will accept that water in a bottle in free fall doesn't flow out because it is weightless and, consequently, unable to exert hydrostatic pressure (in other words, it is pressureless).

The students then need to understand that the upward motion of the bottle and water, after being launched, may be seen as a combination of two motions: one is inertial and the other is free fall. So, whatever the overall direction of motion is (up, down, sideways), if free fall is present, either alone or as one of component motions, the water is weightless and doesn't flow out of the bottle.

Two results of the falling leaky bottle and the bottle launched upwards can be also watched as movies at www.iop.org/EJ/journal/PhysEd.

References

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