Active learning of weightlessness with the bottle-and-water-jet demonstration: Which new experiments do students propose to test an alternative explanation?

J Balukovic¹ and J Slisko²
¹ Druga Gimnazija, Sarajevo, Bosna i Hercegovina;
² Facultad de Ciencias Fisico Matemáticas, Benemérita Universidad Autónoma de Puebla, Puebla, México

jasmina.balukovic@2gimnazija.edu.ba

Abstract. Students learn physics better if they are involved in active learning modes, consisting of different sequences of hands-on and minds activities. The usual way of teaching weightlessness is not adequate for students’ active learning. The concept is typically introduced through “thought experiment” with a free-falling lift in which a person standing on a balance reads “zero weight”. Although some physics textbooks ask students to explain why a water jet stops to flow out of a bottle in free fall, we couldn’t find any experimental study concerned with students’ explanations of this particular demonstration of weightlessness. Therefore, we designed and carry out a corresponding research with students of primary and high schools from Bosnia and Herzegovina and Serbia. The students were asked to explain in a paper-and-pencil format why water flows out of a bottle with a hole when the bottle is at rest? Why does water stop flowing out when the bottle is in free-fall? Propose an experiment that would show that your explanation is right. What should happen in that experiment and why? The students’ answers and drawings revealed many different alternative explanations. They show that active learning of weightlessness might be possible in physics classrooms.

1. Introduction
A popular learning sequence in science and physics education has been Predict-Observe-Explain. As students have various alternative conceptions about physical phenomena, they frequently fail in prediction phase. That outcome can frustrate them and negatively affect their learning. As a remedy, a learner-friendly sequence was proposed recently: Observe-Explain-Propose an Experiment [1].

“Learning is a constructive process in which a student converts words and examples generated by a teacher or presented in a text, into usable skills, such as solving problems. Some of the best problem-solving research has concentrated on the conversion of already encoded knowledge into smooth, fast, skillful problem solving. Thus, instead of investigating only the problem-solving difficulties students encounter, Chi and her group examine, in addition, the difficulties students might have in understanding the worked-out solution examples in the text, prior to solving problems.” [2]

Explanation and argumentation are often discussed by the scientists. Science is less about discovering or memorizing facts, it is more about constructing arguments and considering explanations for
phenomena. Individuals, not just scientists, need to apply same critical skills for personal decision making, participation in societal and cultural affairs, and economic productivity. Thus, students should be engaged in authentic science learning. In other words, they need to learn how to reason and act like scientists in their everyday lives [3].

To support students in writing scientific arguments to explain phenomena, McNeill, Lizotte, Krajcik and Marx [4] developed an instructional framework for work with middle school teachers and students. They used an adapted version of Toulmin’s model of argumentation, developing an instructional framework to reduce the complexity for students, unpack implicit scientific norms, and focus the attention of the learner on the relevant task features. Their instructional framework includes three components: claim, evidence, and reasoning. The claim is a conclusion that answers the original question; it is evidence of scientific data. A justification shows why the data count as evidence support the claim. The reasoning should include the principles the student has applied to the situation. McNeill and Krajcik [5] debated whether to refer to the framework as “scientific explanation” or “scientific argumentation” when working with middle school teachers and students. They decided to refer to it as a framework to explain phenomena.

Berland and Reiser [6] identified three goals of engaging students in scientific practices: (1) sensemaking, (2) articulating, and (3) persuading. They proposed using these goals to understand student engagement and to design instructional interventions to support students. Using a framework as a lens to investigate the question: “What successes and challenges do students face as they engage in the scientific practices of explanation and argumentation?” Through analysis of answers to this question, they find that students consistently use evidence to make sense of phenomena and articulate those understandings, but they do not consistently attend to the third goal of persuading others of their understandings.

2. Treatment of weightlessness in some textbooks in Bosnia and Herzegovina

As in many other countries, some primary school and high-school physics textbooks in Bosnia and Herzegovina introduce the concept weightlessness by using a well-known and frequently used (but questionable) “thought experiment”. When the lift is at rest, the person standing on a balance reads her or his real weight. By contrast, inside a free-falling lift the person floats in the air and the balance shows “zero weight” (Fig. 1).

![Figure 1. Questionable introduction of weightlessness in primary school and high school physics textbooks in Bosnia and Herzegovina.](image)

Introducing weightlessness through this famous “thought experiment” with weighing in a free-falling elevator does not offer students any possibility of sensorial and practical contact with the phenomenon. They are just told something that must be memorized and repeated in order to pass exams:

“If the lift were falling with acceleration $\vec{a} = \vec{g}$, an observer in the lift would be in the weightlessness state, and all the objects would be floating in the lift, too. The bodies would behave as if the gravity were “switched-off”.” [7]
The phenomenon that water is in a state of weightlessness in a free-falling system is mentioned in two of five primary school physics textbooks:

- **Textbook 1:** “Weigh the plastic cup on a scale, and then fill it with water and weigh again. What do you conclude? Water exerts weight on the scale pan. Pour water in the plastic cup up to half and drill a hole at its bottom, water will leak through the hole! Then repeat everything and let the cup fall! In falling the water does not come out from the cup, because it doesn’t have weight.” [8]

- **Textbook 2:** “Drill two small holes near the bottom of a paper cup, and then fill the cup with water. Water will flow out through the holes due its weight. Repeat the experiment in such a way that you drop the filled cup from a sufficiently big height. What do you observe now? While the cup falls, the water doesn't flow out. In the system that falls freely the water is in a state of weightlessness.” [9]

Again, one can easily notice that students were told what they should observe and were given a short explanation. They are not given any opportunity to explore, explain and verify the causal structure of the phenomenon. Only one primary-school physics textbook gives students a real challenge:

“How would you demonstrate that a falling body does not have weight? Think about the experiment, the devices and the way to carry it out. Suppose that a body behaves in air as in vacuum. You can be helped by Internet or, perhaps, by some encyclopedia in library or one you have.” [10]

3. **The idea of this research**

In the spring semester 2015/2016, after completion of topics about gravity and phenomena in a gravitational field, a survey was conducted among students primary and secondary school in Bosnia and Herzegovina and Serbia.

The idea was to examine:

1. students’ explanations of why water stops flowing from a bottle in free fall, and
2. their conceptual and experimental justifications for their explanations.

We intended to carry out an initial study of students’ skills in important elements of scientific work: explaining a phenomenon and providing arguments to support the explanation. Students’ tasks in a paper-and-pencil format were to answer the following questions:

- Why does water flow out of a bottle with hole when the bottle is at rest?
- Why does water stop flowing out when the bottle is in free-fall?
- Propose an experiment that would show that your explanation is right.
- What should happen in that experiment and why?

The first task was an “activation” of students’ explanatory models for an everyday phenomenon. It was interesting to explore whether students would use the same explanatory models for the bottle in free fall. In the second question, the students were asked whether they knew this phenomenon (water stops flowing from a bottle in free fall), and, if so, to describe where and how they learned it. The sources of knowledge of the phenomenon were divided into two groups: schools (if the phenomenon was studied in class) and other sources of information (Internet, TV, personal experience,...). In the fourth question, the students were requested to propose an experiment that would be an argument in favour of their explanatory model. We call these student proposals “argumentative experiments.”

We designed and carried out corresponding research with students of primary and high schools from Bosnia and Herzegovina and Serbia. Students’ explanatory models we expected to find:

- “The air stream doesn’t allow water to flow out from the bottle.”
- “There was no water left in the bottle.”

However, we found an unexpected student explanatory model:

- “Water does not flow out because it goes above the hole.”
Table 1. Percentage of students who suggested argumentative experiments.

| School type         | Bosnia and Herzegovina | Serbia |
|---------------------|-------------------------|--------|
| Primary school      | 47%                     | 41%    |
| Secondary school    | 69%                     | 24%    |

Table 2. Some proposed argumentative experiments by elementary school students in Bosnia and Herzegovina.

| Description of the experiment | Drawing experiment | Number of students |
|-------------------------------|-------------------|--------------------|
| 1. Throw the bottle from a certain height. | ![Drawing](image1) | 2 |
| 2. The bottle was not let fall from some height but would be thrown straight (horizontally). | ![Drawing](image2) | 1 |
| 3. I would do the same, but I would just record with the camera and look at the slow motion. | ![Drawing](image3) | 1 |
| 4. I could prove that gravity acts if we let the water fall freely without any holes, the water would go up again. | ![Drawing](image4) | 1 |
| 5. I suggest an experiment that could be seen live, so that this experiment takes place in front of our eyes. We would throw the bottle to fall freely. | ![Drawing](image5) | 2 |
In what follows, we describe the answers related to the last two questions given by the students who believed the “water goes up” explanation. Many of the proposed experiments are not related to this alternative explanation and, therefore, would be useless for testing explicitly the explanation in an active learning mode. Table 1 shows the percentage of students who suggested argumentative experiments in each country by level of education.

**Table 3.** Some proposed argumentative experiments by high school students in Bosnia and Herzegovina.

| Description of the experiment | Drawing experiment | Number of students |
|------------------------------|--------------------|--------------------|
| 1. Instead of water, put another liquid. | ![Diagram 1] | 1 |
| 2. We would fill the bottle with some liquid and then we would throw it out of the equilibrium position and monitor the raising of the liquid in it. | ![Diagram 2] | 1 |
| 3. Let the elevator fall freely or set up a bottle in a free falling elevator | ![Diagram 3] | 9 |

4. **Results from primary schools and grammar schools in Bosnia and Herzegovina**

In Bosnia and Herzegovina, 267 surveyed students were from I and III grade of high school (Second Gymnasium Sarajevo) and from eighth grade of elementary school (“Ali Nametak” and Elementary School “Grbavica 1”). 105 students in first grade, 60 students in third grade, and 102 students of the eighth grade were surveyed. Some students submitted blank papers, without answering any question. The number of blank papers was 47 (16 in elementary school and 31 in high school). Tables 2 and 3 show typical responses from primary and secondary school students, respectively.

5. **Results from primary schools and high schools in Serbia**

The surveyed students were from three primary schools (primary school “Lazar Savatić”, primary school “Svetislav Golubovic Mitraljeta” and primary school “Svetozar Miletic” – a total of 224 students) and from one high school (Zemun Gymnasium, 109 students). However, only 63 high school students and 211 primary school students provided useful answers. Tables 4 and 5 show typical responses from primary and secondary school students, respectively.

As in Bosnia and Herzegovina, the unexpected explanatory model for water jet absence for a bottle in free fall (“water rises above the hole on the bottle”) was found.
**Table 4.** Some proposed argumentative experiments by elementary school students in Serbia.

| Description of the experiment | Drawing of the experiment | Number of students |
|-------------------------------|---------------------------|--------------------|
| 1. A new experiment would be the same but instead of water we would use Coca Cola or other fluid content. | ![Drawing](image1.png) | 2 |
| 2. If the cap of the bottle was open and the bottle was thrown, in the course of free fall, the water would leak through the cap. | ![Drawing](image2.png) | 1 |
| 3. If we made a hole on the top, then the water would leak at a free fall and not at rest. | ![Drawing](image3.png) | 1 |
| 4. If I spinned the bottled water at sufficient speed, the water would remain in the upper part of the bottle and the water would not press the water level in alignment with a hand so water would not drop. | ![Drawing](image4.png) | 1 |
| 5. Fill the balloon with water and allow it to fall freely. | ![Drawing](image5.png) | 1 |
| 6. In an amusement park, when we go down abruptly, the stomach is lifted up into the weightless condition and therefore we feel sick. | ![Drawing](image6.png) | 1 |
| 7. Record with the camera the action of a whipped bottle that is free to fall. If we looked at the slow-down shot, we would see the water did not fall. | ![Drawing](image7.png) | 1 |
### Table 5. Some proposed argumentative experiments by high-school students in Serbia.

| Description of the experiment                                                                 | Drawing of the experiment | Number of students |
|---------------------------------------------------------------------------------------------|---------------------------|--------------------|
| 1. If we make a hole in the middle of the bottle and allow it to drop freely, water will not leak because the bottle moves too fast to get anything leaked. | ![Drawing](image1)          | 1                  |
| 2. I would take the bottle and lift it up quickly and record with the camera.               | ![Drawing](image2)          | 1                  |
| 3. A ball is in an oblong bowl (like a bottle). When the bowl drops, the ball will go to the top. | ![Drawing](image3)          | 1                  |
| 4. An example of an elevator, when it moves rapidly down, the body inside of it moves up.    | ![Drawing](image4)          | 2                  |
| 5. Fill the bottle with water to the top.                                                    | ![Drawing](image5)          | 1                  |
| 6. If we throw the bottle with water without a cap, the water will go up and get out of the bottle. | ![Drawing](image6)          | 1                  |
6. Discussion of the results and future research

As can be seen from above examples, categories of students’ argumentative experiments are:

1. Essentially the same experiment (example: changing only the height);
2. Nonessential variations of the same experiment (example: coca-cola instead of water or a balloon instead of a bottle);
3. New experiments related to explanation "water goes up" (example: hole in upper part of the bottle or open bottle without a hole);
4. New experiments unrelated to explanation "water goes up" (example: experience in an amusement park).

As can be seen, the students proposed many interesting ideas, such as “throw the bottle horizontally”. Unfortunately, we could not discuss this and other ideas because this was initial diagnostic paper-and-pencil research, carried out in a limited time period. Its goal was to get information about students’ thinking that might enable us to improve the pedagogical approach in physics textbooks.

It should be emphasized that only particular student suggestions, that can be performed in classrooms, were interesting to us because they can show that such thinking (“water goes up”) is not what happens.

Out of all students, only 7 proposed new experiments, logically related to explanatory model “water goes up”. This is not surprising because students in Bosnia and Herzegovina and Serbia, as in other countries, are not usually asked to design experiments or to provide arguments for their claims. Nevertheless, although their number is small, these experiments can be easily carried out to test that explanatory model. In particular, water in an open bottle with no hole will not flow out of the bottle’s mouth in free fall.

It is worth mentioning that the argumentative experiment in which the bottle is thrown horizontally (experiment 2 by a primary school student in Bosnia and Herzegovina) will not necessary disprove the erroneous explanatory model: in the proposed situation water will not flow out! In that way, an erroneous explanatory model, proposed by a student, might sometimes generate a correct prediction. So, as in physics itself, the process of demonstration that an explanation is false is far from simple. To be successful in defending or refuting a proposed explanation, students need more experiences in evidence-based argumentation culture.

This initial research brings promising experimental results that show that active learning of weightlessness could be implemented in physics classrooms. In future research, students should be given additional opportunities to discuss freely between themselves their explanations and argumentative experiments in order to make them better.

Learning outcomes of such experiences (with their own explanations and experiments), similar to real-world scientific practices, would be likely much better than those results obtained only by listening to or reading about “thought experiments”. As can be seen from some of their arguments, students “learned” that in free-falling systems all bodies go up and they applied that erroneous “knowledge” in the case of bottle and water.

This and additional examples of similar active learning experiences (observing, explain and predicting physical events in free-falling systems) would give students a deeper understanding of amazing phenomena, related to the state of weightlessness, that they can easily know by watching many YouTube videos.

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