Teaching and Learning the Concept of Weightlessness: An Additional Look at Physics Textbooks

Jasmina Balukovic[1*]
Josip Slisko[2]

[1]Druga Gimnazija Sarajevo, Sarajevo, Bosnia and Herzegovina
[2]Facultad de Ciencias Físico Matemáticas, Benemérita Universidad Autónoma de Puebla, Puebla, México
*E-mail: jasmina.balukovic@2gimnazija.edu.ba

(Received: 07.12.2017, Accepted: 06.01.2018)

Abstract
A recent textbook research, carried out on a sample of 20 American physics textbooks, shows that the authors mainly keep the old definition of weight. According to that definition, the weight of a body is the gravitational force on the body. In such a conceptual frame, the objects in the spaceship are "apparently weightless" because they are still attracted by the Earth's gravitational force. In addition, almost all authors introduce "apparent weightlessness" using "thought experiment" in which a person finds that her or his "apparent weight" is zero if weighing in a free-falling elevator. The mentioned research was focused on linguistic issues and their role in students' learning the concepts of "weight", "weightlessness" and "free fall". We gave an additional look at 37 physics textbooks in order to analyze the pedagogical treatment of the concept of weightlessness from the point of active physics learning. It is known that students learn physics better when they have multiple opportunities to observe, describe, explain and predict physics phenomena. It was found that only a few authors provide students hands-on and minds-on activities with the concept of weightlessness, limiting their chances to learn it properly. This is a surprising situation because one can find many different demonstrations of free-fall weightlessness published in pedagogical journals that were designed and suggested for their use in physics classrooms.
Keywords: Weightlessness demonstrations, physics textbooks, active physics learning

INTRODUCTION

Amazing videos and photos of uncommon physical phenomena in spaceships (astronauts floating inside, vibrations of a water sphere, spherical candle flames, toys do not function as they do on the Earth,) have caught wide public attention and provoked interest of many people in knowing better what is exactly going up there. Being so, it is not a surprise that "Weightlessness" was included among the most interesting and most important physics topics "every world leader needs to know" (Muller, 2010).

Recently, people are even ready to pay a high price for having first-hand experience of weightlessness. Some of them are so extravagant that they celebrate their wedding in weightlessness. Company Zero-G (www.gozerog.com) makes business providing such moments, using parabolic airplane flights to create such an unusual environment. The concept of parabolic flights was discovered long time ago because NASA used such flights to train their astronauts. The plane was called "Vomit comet" due to the fact it caused airsickness to some astronauts.

That zero-gravity experience got a great media coverage and promotion in 2007, when Stephen Hawking made such a trip in order to have a first-hand enjoyment of weightlessness (http://news.bbc.co.uk/2/hi/science/nature/6594821.stm). In a TED conference (www.ted.com/talks/peter_diamandis_on_stephen_hawking_in_zero_g?language=en#t-221262), Peter Diamandis told an amazing story how it was made possible that Hawking, a world expert in gravity, got experience of zero gravity. It started one day when Hawking confessed to Diamandis that his dream was to travel in space. After long and complicated preparations, due to his delicate health conditions, Hawking experienced weightlessness in eight parabolic flights and was "incredibly happy".

The article is organized in the following way: In the second section, we revisit the relationship between the concepts of weight and weightlessness and related language issues and their importance in teaching and learning of these concepts. In the third section, we present briefly the paradigm of active physics learning and mention some of published demonstrations of free-fall weightlessness that might be used, with adequate didactic designs, to make possible students' active learning of weightlessness phenomena. The fourth section brings the results of our analysis of 37 physics textbooks, carried out to find the presence and the content of students' minds-on and hands-on activities related to weightlessness. In the fifth section, the same analysis was carried out with Prof. Lewin's lecture on weight and weightlessness. The sixth section comments on absence of research on students' learning of weightlessness and presents argument why such research line is needed. In conclusions, we describe the main results of our documental research and provide some suggestions on teaching and learning free-fall weightlessness.

Weight and Weightlessness in American Physics Textbooks: Terminological Issues

To get a clear conceptual account of phenomena that happens in commercial parabolic flights and orbiting spaceships, it is necessary to make a clear relationship between the concepts of "weight" and "weightlessness". The topic was vividly discussed in pedagogical journals, either through individual articles ((King, 1962; Sears, 1963; Iona, 1975) or in a symposium-like form, with the contributions coming from up to five different authors (Iona, Morrison, Brown, Bishop and Sokolowski, 1999).

Resolutions of the conceptualization problem related to relationship between "weight" and "weightlessness" differ from one textbook to another. There are, basically, two main definitions of the term "weight": the "gravitational" and "operational" definitions (Galili, 1995). For the "gravitational" definition, weight of a body is defined as the gravitational force on that body exerted by the Earth or other astronomical body. For the "operational" definition, weight of a body is defined as the force the body exerts on a supporting surface, preventing it from falling.

Inspection of some of the most popular American physics textbooks shows that their authors use "gravitational" definition of weight. Here come four examples:

"The gravitational force that the earth exerts on your body is called your **weight.**" (Young & Freedman, 2008, p. 108)

"The **weight**, W, of an object on the Earth's surface is the gravitational force exerted on it by the Earth" (Walker, 2007, p. 124)

"**Weigh**t… is a force, the pull of gravity acting on an object." (Giancoli, 2005 p. 75)

"The **weight** of an object on or above the earth is the gravitational force that the earth exerts on the object." (Cutnell & Johnson, 2004, p. 90)

The above-mentioned authors consider that the objects in the orbiting spaceship experience an "apparent weightlessness" (Young & Freedman, 2008, p. 146; Walker, 2007, p. 128; Giancoli, 2005, p. 124; Cutnell & Johnson, 2004, p. 136) because they are still attracted by the Earth's gravitational force (together with the spaceship) and, by definition, must have weight. To prepare stage for the concept of "apparent weightlessness", the concept of "apparent weight" is introduced first, using scale reading (equal to "apparent weight") a person would get in an accelerating elevator (Young & Freedman, 2008, p. 145; Walker,2007, p. 126; Giancoli, 2005, p. 124; Cutnell & Johnson, 2004, pp.94-95). A person is in the state of "apparent weightlessness" when her or his "apparent weight" is zero. That can happen inside a free-falling elevator and in orbiting spaceships.

If operational definition of weight is accepted, as a force a body exerts on supporting surface or hanging point, then the weightlessness in those situations is "real weightlessness" because free-falling bodies are unable to exert contact forces between them.

Usually, the concept of "apparent weightlessness" is introduced with a "freely-falling elevator" and "extended" to an "orbiting spaceship". The two situations are very far from students' sensorial and practical experiences. It is not a big surprise that students have conceptual difficulties to gain sound understanding of why and how the bodies behave as being weightless (Gürel & Acar, 2003; Sharma, Millar, Smith & Sefton, 2004; Tural, Akdeniz & Alev, 2010).

In a recent, more complete documental research, carried out with twenty introductory college and university physics textbooks, it was found that language-related issues, such as different, inconsistent, or ambiguous uses of the terms weight, "apparent weight," and "weightlessness," were prevalent (Taibu, Rudge & Schuster, 2015). The physics of the related constructs was not always clearly presented, particularly for accelerating bodies such as astronauts in spaceships, and the language issue was rarely addressed. This unresolved language issue makes teaching and learning of involved concepts very difficult.

A possible way to deal with both the conceptual and language issues, associated with weight and related concepts, is to implement a novel instructional approach based on carefully designed discussions of language and concepts (Taibu, 2015). It turns out that, after instruction, students' interpretations of "weight", "weightlessness" and "free fall" reveal that they are well conversant with the associated language problems. In addition, results indicate that students show contentment in learning that even experts disagree on how to communicate some concepts.

Nobody would disagree that language discussions help students learn to use better physics terminology. Nevertheless, students' real learning of the concept of weightlessness should be demonstrated by their abilities to describe, explain and predict different weightlessness phenomena in multiple contexts. For this to happen, students must be involved in active learning of those phenomena. So, it is important to take another look at physics textbooks, identifying and evaluating the opportunities for active learning of weightlessness they offer to students.

Active Learning of Weightlessness: A Theoretical Base and Practical Possibilities

Active physics learning or activity-based physics learning is gaining popularity in physics education (Meltzer & Thornton, 2012). It is becoming a promising new paradigm that will, sooner or later, replace old paradigm codified in lecture-based teaching and passive students' learning.

> *What is an instruction that promotes active learning? A general answer to this question is: "…Instruction involving students in their own learning more deeply and more intensely than does traditional instruction, particularly during class time." (Meltzer & Thornton, 2012)*

Deep physics learning is likely to occur if students are involved in the "learning cycle", designed by Robert Karplus and based on Piagetian framework of human cognitive development (Karplus, 1977). The cycle consists of three phases:

- *Exploration;*
- *Concept introduction; and*
- *Concept application.*

So, if students should learn about weightlessness, they must have multiple opportunities to explore related phenomena with their own actions and ideas "with minimal guidance and expectation of specific accomplishments" (Karplus, 1977). New experiences should raise questions and complexities that can't be resolved by using accustomed reasoning patterns. Such situations lead to a mental disequilibrium and students are ready for self-regulation.

In the second phase, a new concept or principle is introduced, making possible that students apply new pattern of reasoning on their experiences, gaining again a mental equilibrium.

In the third phase, students should apply new concept and/or reasoning pattern in additional situations.

As the phenomena related to weightlessness in spaceships are so uncommon and counter-intuitive, numerous articles were published in physics teaching journals with aim to show that was possible to demonstrate some of these phenomena on the ground, in a classroom or in a school yard (Kruglak, 1962 and 1963; Chakarvarti, 1978; Smith, 1989; LaCombe & Koss, 2000).

Many of these demonstrations could be useful for students to learn actively weightlessness phenomena. The causal understanding of these phenomena is much easier with the idea that inside of free-falling systems gravity force and all gravity-related forces (for instance, friction force and buoyant force) disappear, while other forces (for instance, elastic force, magnetic force or electrostatic force) are not affected when the system performs free fall. In other words, although the gravity force is responsible for free fall of the system, for an observer inside of the system the objects behave in the same way as those objects being in gravity-free environment.

As an example, let us see one demonstration, proposed by Kruglak (Kruglak, 1963):

> *"Attach a lead sinker to one end of a spring or rubber band; attach the other end to a large cork. Place the system in a tall cylinder with the sinker at the bottom. Fill the cylinder with water. Choose a spring such that the tension will allow some of the cork to be above the water surface. Drop the cylinder to a catcher. The buoyant force during the free fall becomes zero, but the elastic force of the spring will pull the cork under the water surface."*

For a non-inertial observer, falling freely with the cylinder, the absence of the buoyant force is a natural consequence of the absence of gravity force inside the cylinder and the observed motion of the cork is easily understood. For an inertial observer, standing on the ground, the explanation of cork's motion relative to the cylinder is much more complicated.

NASA, working for a wide societal promotion of its important technological micro-gravity research, has also provided manuals for teachers that contain elaborated students' practical and learning activities related to the weightlessness (Vogt, Gregory & Wargo, 1992). An important suggestion for teachers, not present in any of Kruglak's demonstrations (Kruglak, 1962 and 1963), is that these demonstrations are more effective if students are asked to predict what would happen before they see or carry out a demonstration of free-fall weightlessness.

In this way, educational community had at its disposal all the necessary elements for implementing active learning of weightlessness phenomena:

(1) A theoretical framework of "learning cycle";
(2) Many demonstrations of free-fall weightlessness, suited for students practical and conceptual explorations; and
(3) Explicit suggestion that the demonstrations are more effective when students are asked to describe, explain or predict explored phenomena.

Opportunities for Active Learning of Weightlessness in American Physics Textbooks

Taking into account the existence of the mentioned elements, it is very surprising that in 37 American introductory physics textbooks we have analyzed in this documental research (17 of them are were not included in previously mentioned research on language issues that was carried out on 20 physics textbook (Taibu, Rudge & Schuster, 2015)), there are only a few suggested demonstrations regarding students' hands-on or mind-on activities related to near-ground free-fall "apparent weightlessness".

For example, Hecht proposed a kinesthetic activity to give students a chance to experience free-fall "effective weightlessness":

> *"**Weightlessness & Free-Fall:** Hold your palm facing up, and place a bunch of keys in it, keeping your hand open. Now drop your arm, accelerating it at 9.8 m/s^2. The keys descend at this rate all by themselves – let them fall freely and simply have your hand precede them down. At the point where your hand reaches a = g, you will no longer feel the keys pressing on your palm; your hand will fall away as the keys fall, and the keys will become effectively weightless. Put the keys back in your open "stationary" hand and step off a chair. As you descend, the keys will again weightless and you'll feel them thump down into your hand when you hit the floor." (Hecht, 2000, p. 209)*

Instead of suggesting a hands-on demonstration of buoyancy absence in free-falling water, given above in Kruglak's description (Kruglak, 1963), and asking students to describe and explain what they saw in that demonstration, many authors situate explanatory tasks in the contexts of orbiting space stations, satellites and spacecrafts:

> *"Suppose that an orbiting space station of the future had a swimming pool in it. If there is no artificial gravity, would a buoyant force be exerted on a swimmer? Explain." (Cutnell & Johnson, 2004, p. 329)*
> *"A block of wood floats half submerged in a container of water. If the same container were in an Earth-orbiting satellite, how would the block float? Explain your reasoning." (Jones & Childers, 1999, p. 336)*

"Does Archimedes' principle hold in a satellite orbiting the Earth in a circular orbit? Explain." (Tipler & Mosca, 2003, p. 417)

"Is Archimedes' principle applicable in a spacecraft orbiting the Earth? Explain carefully." (Lane, 2000, p. 518)

All these contexts are "thought experiments" for students to think about because they aren't in position to explore actively the physical phenomenon they are supposed to learn and understand. Only one author is making use of the situation in Kruglak's demonstration, as a base for a conceptual question:

> 'A ping-pong ball is attached to the bottom of a pail by a rubber band. The pail is then filled with water until the ball is at rest below the surface of the water . . .. The pail, with water, ball, and rubber band, is then carried to the top of a tall building and released from rest at the edge of the roof. The motion of the ball relative to the pail is then best described as follows:
>
> *(a) The ball moves initially toward the bottom of the pail.*
> *(b) The ball initially moves toward the surface of the water.*
> *(c) The ball remains at rest below the surface of the water.*
> *(d) None of the above correctly describes the motion of the ball during the fall off the roof.' (Blatt, 1989, pp. 253 - 254)*

Nevertheless, by saying that the pail should be carried to the top of a *tall building* and released from rest at the edge of the roof, students might be misled and get erroneous idea that the phenomenon occurs only in a long free fall. The truth is different. Initial height should not be very big because the ball moves towards to the bottom of the pail almost instantly after the pail was released. This was demonstrated with different set of objects: small inflated balloon, spring and plastic bottle instead of ping-pong ball, rubber band and pail (Slisko & Planinsic, 2010).

Other authors use also very unlikely contexts for conceptual questions related to weightlessness:

> *"A man goes over Niagara Falls in a barrel with windows in the side. During the descent, the man takes out an apple, holds it up in front of his face and releases it. Describe what is seen by (a) an observer on the bank looking through the window and (b) the man in the barrel." (Jones, R. Childers, 1999, p. 134)*

A National Geographic televised story gives evidence that going over Niagara Falls in a barrel is a life-threating event (http://channel.nationalgeographic.com/videos/niagara-barrels). So, nobody would play with an apple during such a free fall and if someone would, nobody from the bank could see what is going inside the barrel.

The only demonstration of free-fall weightlessness, found in three of 37 American physics textbooks we have analyzed, can be traced back to the demonstrations of Kruglak (1963) and Edge (1987). Here come their descriptions and explanations:

> *"Drill or punch a small hole near the bottom of a tall tin can. Stopper the hole and fill the can with water. Hold the can several feet above a basin and remove the stopper so that water can flow out of the hole. Drop the can so that an assistant can catch it above the basin. During the free fall the flow of water will cease. The water and the container will be falling together and the water does not leave the container." (Kruglak, 1963)*
>
> *"… You poke two holes close to the bottom of a paper cup… The cup is filled with water, which pours out of the two holes. Now climb a step ladder, hold the cup high at arm's length, and drop it, preferably into a trash can. No water runs out as the cup falls …, the*

water is "weightless" in the falling system. Gravitational forces are absent in the accelerated system" (Edge, 1987, Experiment 1.28 Weightlessness)

Beside trivial differences in the number of holes (one vs. two) and the type of container (tall tin can vs. paper cup), there is a much more important difference in the ways Kruglak and Edge explain the fact that the water does not flow out of container during free fall. Kruglak's explanation is kinematical (falling together), while the explanation of Edge is dynamical (absence of gravitational force in accelerated system).

In another collection of physics demonstrations, corresponding explanation part is much more sophisticated:

"At one level, this demonstration is "simply" an illustration of the concept of weightlessness in freely falling reference frames. At another level, it illustrates the concept underlying Einstein's Equivalence Principle – which states the locally gravity is equivalent to being in an accelerated reference frame." (Ehrlich, 1997, p. 183)

Let us analyze now the differences in three physics textbook presentations of this popular demonstration. The first (and curious) difference is that Wilson, Buffa and Lou (2007) present their version of the demonstration after introducing the concept of "apparent weightlessness", while Hewitt (2010) and Hecht (2000) inserted it in the domain of fluids.

Wilson, Buffa and Lou (2007, p. 253) present a photo of a plastic cup from which two jets of water flowing out. Their photo is similar to the one in the Figure 1.

Figure 1. *Two jets flowing out of a plastic cup*

The photo is the basis for the following question:

"If the cup… were dropped, no water would run out. Explain." (Wilson, Buffa & Lou, 2007, p. 253)

So, in this presentation, students are not supposed to carry out the demonstration, they are shown a photo and told what would happen if the cup, with flowing jets, were dropped. Their only task is to explain why water does not flow out of the cup in free fall.

Hewitt presents the demonstration in this way:

"If you punch a couple of holes in the bottom of a water-filled container, water will spurt out because of water pressure. Now drop the container, and, as it freely falls, note that the water no longer spurts out! If your friends don't understand this, could you figure it out and then explain it to them?" (Hewitt, 2010, Project 2, p. 243)

So, students are supposed to carry out the demonstration, they are told that water flows out due to its hydrostatic pressure, they are informed what they will see and, finally, their task is to figure out an explanation.

A much better potential for active learning of weightlessness with this demonstration can be found in a book for students whose ages are between 10 and 13 years:

> "1. Use a nail to make two holes on opposite sides near the bottom of a Styrofoam cup…
>
> 2. Take the cup outside, put your fingers over the holes, and fill the cup with water.
>
> 3. Hold the cup as high above the ground as possible. Then release the cup.
>
> What happens to the water streams as the cup falls? How can you explain what you observe?" (Gardner, 2010, pp. 121-125)

So, young students using this book have a sequence of observation, description and explanation tasks. The same sequence is applied to two additional demonstrations of free-fall weightlessness, not found in analyzed physics textbooks. It is important to comment, that other books for young students give them task to perform the demonstration but without any conceptual learning task beside practical performance (Spilsbury & Spilsbury, 2016; Rey, 2015). After that, students are given explanations of what they might have seen. Some of these explanations are rather superficial and one is even wrong:

> "Water does not come out of the open hole while the cup falls. This because the water is accelerating as fast as the cup, and the downward force of water is balanced by the upward push from the cup." (Spilsbury & Spilsbury, 2016, p. 11)

Hecht presents a little bit strange version of the falling-cup demonstration:

> ""Weightless" & Pressureless: For a weightless fluid, one far out in space, no internal pressure exists. (That's true provided the amount of fluid is modest, and its self-gravity in negligible. Such is not the case for something huge as a star.) Take a paper cup filled with water, punch a small hole in the side near the bottom, and watch the pour out in thin steam. Now drop the cup. What happens to the stream while the cup falls? What would happen if it accelerated upward?" (Hecht, 2000, p. 364]

In this case, students are also supposed to carry out the demonstration. It is good idea that students, instead of being told about what happens to the steam, find by their own observations what happened. After that, students should predict what would happen if the cup were accelerated upward.

What is missing in Hecht's presentation is an explanatory task for students (why water steam does not flow out in free fall?). With that task, students would have an opportunity to practice an active learning sequence designed and promoted by Etkina and van Heuvelen (2007). That sequence, in resonance with Karplus' learning cycle, starts with an observational experiment in which students have direct experience of a studied phenomenon. After that they should figure out different explanations for what they observed. Finally, based on different explanations, student should predict the outcome of a testing experiment. In this approach, students' abilities to formulate a prediction are significantly enhanced by a previous explanatory task.

In addition, Hecht's prediction task is not well defined because there are two possible answers. If the cup were accelerated upward, the jet would flow out with bigger speed than when the cup is at rest. If the cup were launched up in free rise (after losing the contact with the hand), the jet would stop flowing out. It is strange that Hecht doesn't suggest that students verify their prediction, whatever it is.

In a pilot research, it was found that students use their kinesthetic experience of feeling heavier in an elevator accelerating upward to predict that the water jet from a bottle in free rise (as being heavier) will flow out faster. They are very surprise when they observe that such a prediction is wrong: in free rise, the water jet stops flowing out (Corona, Slisko & Planinsic, 2006).

Weightlessness Demonstrations in Prof. Lewin's Classroom

It is clear that some physics teachers might have a wide pedagogical repertoire that no physics textbook can match. In their classrooms, students may see some practical demonstrations of free-fall weightlessness different from the one with free-falling cup we have found in three of 37 physics textbooks.

An example might be YouTube lecture "*Weight, perceived gravity and weightlessness*" delivered by MIT Professor Walter Lewin (Lewin, https://www.youtube.com/watch?v=M0mxyPOMcw0, 2016). That 50-minute lecture has three main parts, carefully ordered:

(1) Concepts' introduction and application;

(2) Low-tech and high-tech classroom demonstrations of weightlessness; and

(3) Video presentation of weightlessness inside a plane performing a free (engines-off) parabolic motion.

As it was said, the concept of weight is a very controversial one. Although Prof. Lewin recognizes it, saying explicitly that weight is a non-intuitive and tricky "thing", he introduces it straightly (and quite unorthodoxly!) as the upward force F_S a scale exerts on the body being weighted (Figure 2).

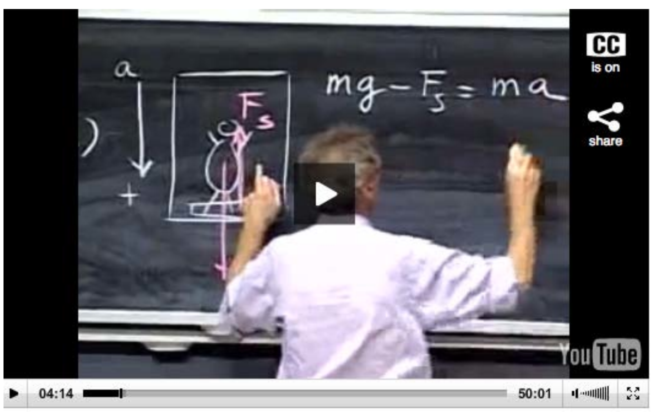

Figure 2. *Prof. Lewin is introducing (verbally, visually and symbolically) the concept of the weight as the "force of scale" F_S acting upwards on what is being weighing*

Prof. Lewin presents two types of free-fall demonstrations of weightlessness. The first type is low-tech one, carried out with a one - gallon water container, similar to that proposed by Hecht to be performed by students (Hecht, 2000). Initially, Prof. Lewin holds the container in his hands, standing on the table (not a very common position of a physics lecturer!), and later jumps from the table, separating his hands slightly from it (Figure 3). Not surprisingly, the container and Prof. Lewin fall in the same way, keeping their spatial configuration unchanged.

Figure 3. *Prof. Lewin is performing a low-tech classroom demonstration of weightlessness of a gallon of water in free fall*

The second type of weightlessness demonstration is a high-tech one, showing that two sensitive electronic balances, in free fall, don't register a weight of an attached object. The balances were designed and made at the MIT. It is very important to stress that, before performing both type of demonstrations, Prof. Lewin tells students what they are going to observe. In the third part, students are shown videos clips about weightlessness experiences of persons on board of a plane moving along a parabolic path with engines off. As Prof. Lewin's way of teaching is to do and tell everything, students are not given any opportunity for active learning of the concepts of weight and weightlessness.

RESEARCH ON LEARNING OF WEIGHTLESSNESS

Physics Education Research (PER) deals with all aspects of physics learning and teaching. New name of its leading and exclusive journal "Physical Review – Physics Education Research" is strong evidence that this research line is now an integral part of physics itself. In a few decades of existence, PER has generated an impressive theoretical and experimental knowledge on conceptual difficulties students face when they learn physics (McDermott & Redish, 1999) and how physics should be taught in order to reduce or eliminate these difficulties (Meltzer & Thornton, 2012).

Taking into account big public interest in and scientific importance of weightlessness phenomena, it is surprising that students' conceptual understanding of near-ground free-fall manifestations of weightlessness was not (and still is not) in focus of PER. Rare research articles (Gürel & Acar, 2003; Sharma, Millar, Smith & Sefton, 2004) are mainly focused on students' understanding of weightlessness in orbiting satellites.

Possible reasons are somehow related to controversial character of the concept weightlessness (apparent vs. real) and to the situation that only one of many weightlessness demonstrations, designed for classroom teaching, has found its way into very limited number of physics textbooks. Our documental research has identified only three such textbooks.

As it was commented above, the design of students' active learning tasks, proposed by textbook authors, is not ideal. Nevertheless, it would be interesting to explore how students explain observation that water does not flow out from a free-falling cup (a students' task sometimes given (Wilson, Buffa & Lou, 2007; Hewitt, 2010) and sometimes curiously absent (Hecht,2000)).

In a recent initial research (Balukovic & Slisko, 2015), carried out with 100 high-school students in Sarajevo (Bosnia and Herzegovina), it was found that 20 students have an alternative explanation for such a phenomenon: The water jet doesn't flow out in free fall, because the water goes up, placing itself above the hole (Figure 4).

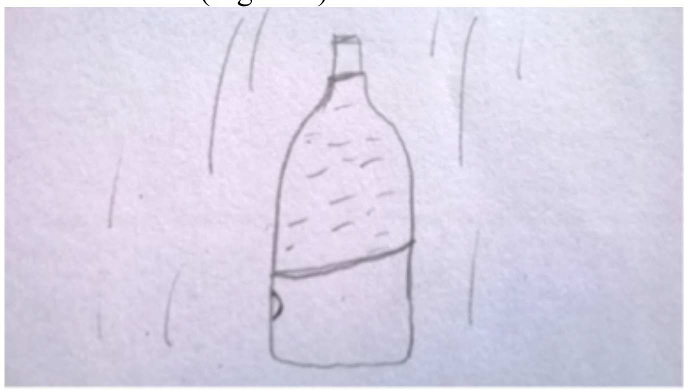

Figure 4. *A student's drawing that illustrate an alternative explanation of the absence of water jet in free fall*

Some students even give an argument why it should be so: water has bigger mass and falls more slowly than the bottle. The same argument was given by students in another pilot research related with a completely different demonstration of weightlessness in which a plastic container, a weight and an inflated balloon were used (Balukovic, Slisko & Corona, 2015).

These preliminary results show that students face conceptual difficulties when they have to explain their observations of free-fall weightlessness phenomena. To design appropriate active learning sequences, more research is needed to identify experimentally and understand theoretically the factors that influence students' thinking related to explanation and prediction of physical events in free-falling systems.

CONCLUSIONS

Out of 37 analyzed introductory physics textbooks, published in the USA, only three present a demonstration of free-fall weightlessness (water jets do not flow out of a free-falling plastic cup). All versions of the demonstration offer students different initial opportunities for active learning of weightlessness. Nevertheless, the design of learning sequences could be enriched and improved by using either Karplus' "learning cycle" (exploration, concept introduction, concept application) (Karplus, 1977) or ISLE methodology (observational experiment, explanation, testing experiment) (Etkina & van Heuvelen, 2007).

In order to check real students' comprehension of free-fall weightlessness only one single demonstration, even with the best possible structure (carry out, observe, describe, explain), is far from being enough. Indeed, research shows that students reveal their real conceptual understandings only if they are able to transfer knowledge acquired in one particular context into new contexts (Bransford, Brown & Cocking, 1999; Kober, 2015). This implies that, for better learning results, students should actively deal with different weightlessness phenomena occurring in free-falling systems.

Fortunately, in addition to Kruglak's collection of demonstrations presented long time ago (Kruglak, 1962 and 1963), recently new proposals were published, too (Balukovic, Slisko & Corona, 2015; Sliško & Corona, 2011; Mayer & Varaksina, 2015). One of them (Ayala, Slisko & Corona, 2011) initially imagined by a student, shows that that active learning of weightlessness phenomena has a great potential to promote students' creativity. Needless to say, among XXI century skills, urgently needed for constant growth of knowledge-based economy, creativity thinking occupies certainly a central role (Trilling & Fadel, 2009).

In addition, weightlessness phenomena in free-falling systems, easily created in classroom, can be more efficiently observed and analyzed thanks to fast video cameras. Observation and explanation of fine details, usually hidden to naked eye, could be challenging learning tasks for students. A convincing evidence for existence of such learning tasks are interesting results obtained in video analysis whose aim was to explore when and how water stops to flow out from a free-falling bottle (Balukovic, Slisko & Corona, 2015).

Due to their counter-intuitive character, weightlessness phenomena are well suited for active (hands-on and minds-on) learning. In order that it becomes a classroom reality, physics textbooks and teachers should offer to students more connected opportunities to explore actively physical events in free-falling systems.

ACKNOWLEDGMENT
The authors thank sincerely to Dr. Rex Taibu for his kind help in preparation of this article.

REFERENCES

Ayala, H., Slisko, J. & Corona Cruz, A. (2011). Magnetic demonstration of weightlessness: a spark of student creativity. *The Physics Teacher, 49*(8), 524-525.

Balukovic, J., Slisko, J. & Corona Cruz, A. (2015). ¿Cómo deja de fluir un chorro de agua de un recipiente en caída libre? *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias, 12*(3)**,** 593-600.

Balukovic, J., Slisko, J. & Corona Cruz, A. (2015). Electrostatic demonstration of free-fall weightlessness. *Physics Education, 50*(3)**,** 288-290.

Balukovic, J., Slisko, J. & Corona Cruz, A. (2015). A demonstration of "weightlessness" with 1-kg mass and balloon. *The Physics Teacher, 53*(7)**,** 440-441.

Balukovic, J. & Slisko, J. (2015). Bottle-and-water-jet demonstration of free-fall weightlessness: Do high-school students know it and what are their explanations? Poster presented at the GIREP conference, Wroclaw, Poland.

Blatt, F. J. (1989). *Principles of Physics.* 3rd edition Boston: Allyn and Bacon.

Bishop, R. (1999). Weight—an accurate, up-to-date, layman's definition. *The Physics Teacher, 37*(4), 238 – 239.

Bransford, J. D., Brown, A. L. & Cocking, R. R. (1999). *How people learn: Brain, mind, experience, and school*, Washington, DC: The National Academies Press,

Brown, R. (1999). Weight—don't use the word at all. *The Physics Teacher, 37*(4), 241.

Chakarvarti, S. K. (1978). A demonstration on weightlessness. *The Physics Teacher, 16*(6), 391.

Corona Cruz, A., Slisko, J. & Planinsic, G. (2006). Freely rising bottle of water also demonstrates weightlessness. *Physics Education, 41*(3), 208-209.

Cutnell, J. D. & Johnson, K. W. (2004). *Physics*. Sixth Edition. New York: John Wiley & Sons.

Edge, R. D. (1987). *String and sticky tape experiments*. College Park: American Association of Physics Teachers.

Ehrlich, R. (1997). *Why Toast Lands Jelly-side Down: Zen and the Art of Physics Demonstration* Princeton: Princeton University Press.

Etkina, E. & van Heuvelen, A. (2007). Investigative science learning environment—a science process approach to learning physics. In E. F. Redish & P. J. Cooney (Eds.), *Research-*

based reform of university physics, College Park: American Association of Physics Teachers, p. 1- 48.

Galili, I. (1995). Interpretation of students' understanding of the concept of weightlessness. *Research in Science Education, 25*(1), 51-74.

Gardner, R. (2010). *Forces and motion science fair projects, revised and expanded using the scientific method*, Berkeley Heights, NJ: Enslow Publishing.

Giancoli, D. C. (2005). *Physics. Principles with Applications*. Sixth Edition. Upper Saddle River, NJ: Pearson/Prentice Hall.

Gürel, Z. & Acar, H. (2003). Research into students' views about basic physics principles in a weightless environment. *Astronomy Education Rev*iew, *2*(1), 65-81.

Hecht, E. (2000). *Physics: Calculus*. Second Edition, Pacific Grove, CA: Brooks/Cole.

Hewitt, P. G. (2010). *Conceptual Physics*. Eleventh Edition. Boston: Addison-Wesley.

Iona, M. (1975). The meaning of weight. *The Physics Teacher, 13*(5), 263-274.

Iona, M. (1999). Weight—an official definition. *The Physics Teacher, 37*(4), 238.

Jones, E. & Childers, R. (1999), *Contemporary College Physics.* 3rd edition. Boston: WCB/McGraw-Hill.

Karplus, R. (1977). Science teaching and the development of reasoning. *Journal of Research in Science Teaching, 14*(2), 169-175.

Kober, N. (2015). *Reaching Students: What Research Says About Effective Instruction in Undergraduate Science and Engineering*. Washington, D.C.: The National Academies Press.

Kruglak, H. (1962). Demonstrations of weightlessness. *American Journal of Physics, 30*(12), 929-930.

Kruglak, H. (1963), Physical effects of apparent "weightlessness". *The Physics Teacher, 1*(1), 34-35.

King, A.L. (1962). Weight and weightlessness. *American Journal of Physics, 30*(5), 387.

LaCombe, J. C. & Koss, M. B. (2000). The make-it-yourself drop-tower microgravity demonstrator. *The Physics Teacher, 38*(3), 143-146.

Lane, R. R. (2000). *University Physics.* Pacific Grove, CA: Brooks/Cole.

Lewin W., (2016). Lecture 7 "Weight, Perceived Gravity, and Weightlessness", Course 8.1 "Classical Mechanics", https://www.youtube.com/watch?v=M0mxyPOMcw0.

Mayer, V. V. & Varaksina. E. I. (2015). A simple demonstration of Einstein's lift: a body thrown upwards moves rectilinearly and uniformly relative to a free-falling model of the lift. *European Journal of Physics, 36*(5), 055020.

McDermott, L. C. & Redish, E. F. (1999). Resource letter: PER-1: Physics education research. *American Journal of Physics, 67*(9), 755-767.

Meltzer, D. E. & Thornton, R. K. (2012). Resource Letter ALIP–1: Active-Learning Instruction in Physics. *American Journal of Physics, 80*(6), 478-496.

Morrison, R. C. (1999). Weight and gravity—the need for consistent definitions. *The Physics Teacher, 37*(1), 51 – 52.

Muller, R.A. (2010). *Physics and technology for future presidents. An introduction to essential physics every world leader needs to know.* Princeton: Princeton University Press, Section "You have weight, but you feel weightless", 75-76.

Rey, H. A. (2015). *Curious George Discovers Space*. New York: Houghton Mifflin Harcourt.

Sears, F. W. (1963). Weight and weightlessness. The Physics Teacher, *1*(1), 20-23.

Sharma, M. D., Millar, R. M., Smith, A. & Sefton, I. M. (2004). Students' understandings of gravity in an orbiting space-ship. *Research in Science Education, 34*(3), 267-289.

Slisko, J. & Corona Cruz, A. (2011). Showing weightlessness with magnetism. *Physics Education, 46*(5), 525-527.

Slisko, J. & Planinsic, G. (2010). Hands-on experiences with buoyant-less water. *Physics Education, 45*(3), 292-296.

Smith, C. J. (1989). Weightlessness for large classes. *The Physics Teacher, 27*(1), 40-41.

Sokolowski, A. (1999). Weight—a pictorial view. *The Physics Teacher, 37*(4), 240 – 241.

Spilsbury, R. & Spilsbury, L. (2016). *Ride That Rollercoaster: Forces at an Amusement Park*, Chicago: Heinemann-Raintree.

Taibu, R. A. (2015). Study of Conceptual and Language Issues Surrounding Weight, Weightlessness, and Free Fall: Textbook Analysis, Instructional Design, and Assessment. *Dissertations.* Paper 596. http://scholarworks.wmich.edu/dissertations/596

Taibu, R., Rudge, D. & Schuster, D. (2015). Textbook presentations of weight: Conceptual difficulties and language ambiguities. *Physical Review Special Topics - Physics Education Research*, **11,** 010117-1-010117-20.

Tipler, P. A. & Mosca, G. (2003). *Physics for Scientists and Engineers.* 5th edition, New York: W. H. Freeman.

Trilling, B & Fadel, C. (2009). *21st century skills: Learning for life in our times*. New York: John Wiley & Sons.

Tural, G., Akdeniz, A. R. & Alev, N. (2010). Effect of 5E teaching model on student teachers' understanding of weightlessness. *Journal of Science Education & Technology, 19*(5), 470-488.

Vogt, G. L. & Gregory, M. J. (1992). Wargo (Eds), *Microgravity: A Teacher's Guide with Activities*. Washington, D.C.: National Aeronautics and Space Administration.

Walker, J. S. (2007). *Physics*. Third Edition. Upper Saddle River, NJ: Pearson/Prentice Hall.

Wilson, J. D., Buffa, A. J. & Lou, B. (2007). *College Physics*. Sixth Edition. Upper Saddle, NJ: Pearson/Prentice Hall.

Young, H. D. & Freedman, R. A. (2008). *Sears and Zemansky's University Physics*. 12th Edition. Volume 1. San Francisco: Pearson/Addison Wesley.