FACTA UNIVERSITATIS
Series: **Physics, Chemistry and Technology** Vol. 21, Nº 1, 2023, pp. 57 - 75
https://doi.org/10.2298/FUPCT2301057K

Original scientific paper

STIMULATING CREATIVE THINKING IN STUDENTS WITH SIMPLE EXPERIMENTS ON EINSTEIN'S EQUIVALENCE PRINCIPLE IN PRIMARY AND SECONDARY EDUCATION

UDC 371.3 : 53 : 371.671/695

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Abstract. *The same instructional units on Gravity and Weightlessness were approached in two different ways: through a traditional method that doesn't rely solely on teacher-led lectures but combines various established teaching techniques, and through the novel Predict-Observe-Explain approach, incorporating the implementation of two new experiments designed to enhance physics education. This pilot study aimed to assess the stimulation of students' creative thinking, specifically in the 7th grade of primary school and the 1st grade of high school. The results indicated that students who engaged with the innovative teaching approach demonstrated a higher level of creativity.*

Key words: *weightlessness, classrooms experiments, predict-observe-explain approach, creative thinking*

Received: November 18th, 2023; accepted: December 24th, 2023
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1. INTRODUCTION

Local disappearance of the gravitational field in a freely falling reference system is a consequence of its non-inertial nature, i.e., accelerated motion. Einstein, contemplating this, arrived at the idea that the existence of gravitational field is relative. The equality of gravitational and inertial mass is key to reaching this conclusion. In Newtonian mechanics, the equality of these masses is considered a coincidence, causing all bodies in free fall to have the same acceleration.

Einstein's idea is that the equality of these two masses is not accidental but represents a manifestation of the equivalence that exists in nature between gravity and inertia. In accordance with the General Theory of Relativity, bodies always move according to inertia, i.e., along geodesic lines - the shortest paths between two chosen points. Although the real gravitational field of the Earth is central, in small regions of space, it can be considered homogeneous. Therefore, for small paths (such as those in laboratory conditions) during free fall, the principle of equivalence holds (Hobson et al., 2006).

For this reason, experiments conducted in a straightforward manner, utilizing the free fall of a system in the everyday environments of students - classrooms, laboratories, or their workspaces, play a significant role in fostering students' critical and creative thinking. Given that such experiments can be executed using readily available resources without substantial financial investments, and that various teaching scenarios can be developed based on them, it necessitates educators' readiness to innovate their approach to student engagement. In our article, we will present an illustrative case of implemented class sequences that contributed to a transformation in the expression of creative ideas among seventh-grade students in elementary school and first-year students in high school.

The pilot research we conducted was centered on the implementation of a novel experimental design and teaching approach within the context of studying weightlessness, undertaken in seventh-grade classes at an elementary school, comprising two sections, as well as in the first year of a high school, also comprising two sections. Besides the fact that the new experiments, for which we assert, according to available literature and teacher interviews, had not been previously integrated into physics education, this study concurrently demonstrates their influence on enhancing the expression of creative ideas among students and the cultivation of their creative thinking.

Subsequently, the following section will elucidate the following:

- Research objectives;
- Description of experiments;
- Research procedure;
- Creative thinking;
- Results and discussion;
- Conclusion and further research.

2. Research Objective

Our pilot study had essentially two primary objectives. The first objective was to enhance the understanding of weightlessness among students. The second objective was to stimulate creative thinking through the implementation of novel experiments. It is evident that these two objectives overlap with each other, and they can be unified into a single goal, which can be formulated as: Promoting the development of creative thinking by incorporating new and intriguing experiments in physics education lessons that integrate the concept of weightlessness.

3. Description of Experiments - Absence of Hydrostatic Pressure; Absence of Buoyancy Force in Weightlessness - Magnetic Demonstration

Numerous experiments on weightlessness can be readily performed in classrooms or assigned as students' homework. When it comes to the absence of buoyant force in weightlessness, experiments involving the Cartesian diver (Sliško, 2020) and the presence of an air bubble (Sliško and Garduno, 2022) are particularly significant. However, for our pilot study, we included two experiments (Krulj and Sliško, 2023). If students are already somewhat familiar with certain experiments, there is a risk that we might not obtain a clear picture of how experiments stimulate their thinking and the generation of new ideas. With entirely new experiments in teaching, to which students are exposed for the first time, we expected to encourage curiosity that can precede a creative approach to their work.

In the first experiment, we enhanced the existing free-fall experiment of a container with an opening at the bottom, filled with water (Kruglak, 1963), where the water ceases to flow due to the absence of hydrostatic pressure in a weightless state. We extended this concept by introducing a situation in which, during free fall, a sealed container with an opening at the bottom and partially filled with water would experience the entry of air bubbles into the container. In a state of equilibrium, when the container is at rest, the air pressure (p_1) inside the container and the hydrostatic pressure (p_h) acting on the opening from the interior of the container, are balanced with atmospheric pressure (p_a) acting on the opening from the outside.

The Pressure equilibrium is given by equation 1:

$$p_1 + p_h = p_a \tag{1}$$

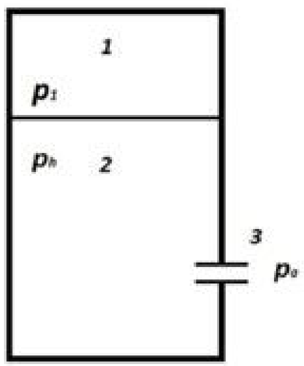

Fig. 1 The container at rest; 1-air, 2-water, 3-open tube

However, during free fall, the disappearance of hydrostatic pressure leads to an imbalance where the pressure around the container is greater than the air pressure inside (Sliško et al., 2021) the sealed container. This causes a certain amount of air to enter the container from the outside, manifested by the appearance of air bubbles in the water within the container near the opening (Figure 2). During the free fall of a container, due to the local disappearance of the gravitational field in the falling container, hydrostatic pressure is nonexistent, resulting in a specific gradient between external static pressure and the air pressure inside the container. Over time, the external static pressure decreases in the case of a container moving through the air by the current amount of hydrodynamic pressure (i.e. aerodynamic pressure), following Bernoulli's principle. Aerodynamic pressure increases with the increasing velocity of the container falling through the air. As the external static pressure acting on the opening of the container decreases with the increasing velocity of the container in free fall, and the pressure inside the air bubble rises, the pressure gradient also decreases until equilibrium is established. The experiment was conducted over a short time interval along a brief path, during which the formation of air bubbles of a certain volume in the water near the opening of the container was observed. The pressure equilibrium established at a specific moment during free fall, corresponding to the formation of a certain volume of an air bubble, marks the point where the air bubble's volume no longer increases, as described by equation 2.

$$p_1 + p_4 = p_{out} \tag{2}$$

where p_1 is the air pressure in the container above the water, p_4 is the air pressure in the air bubble inside the container near its opening, and p_{out} is the external static pressure at the moment of establishing the pressure equilibrium.

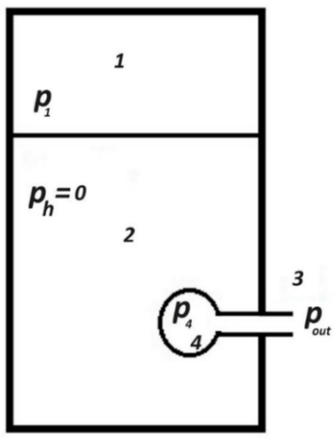

Fig. 2 The container in weightlessness (at one moment during free fall); 1 - air, 2 - water, 3 - open tube, 4 - air bubble

In second experiment, we utilized a container (Figure 3) filled with water. At the bottom of the container, a magnet was securely attached. Within the water, a steel tea ball was submerged, inside of which we placed a table tennis ball. In a state of rest, the tea ball with the table tennis ball floated on the water's surface.

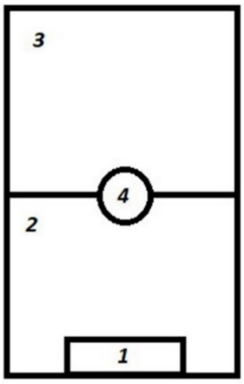

Fig. 3 a) The container at rest; 1 - magnet, 2 - water, 3 - air, 4-steel tea ball with table tennis ball inside

The equilibrium of the forces acting on the floating ball is given by equation 3:

$$\overrightarrow{F_g} + \overrightarrow{F_m} = \overrightarrow{F_b} \tag{3}$$

Where F_g is gravitational force, F_m is magnetic force, F_b is buoyant force.

As the water container (sealed to prevent any spillage during its free fall) descended along a trajectory of approximately 2 meters, the steel ball, due to the absence of buoyant force, was subject to the influence of magnetic interaction and was drawn towards the container's bottom (Figure 4).

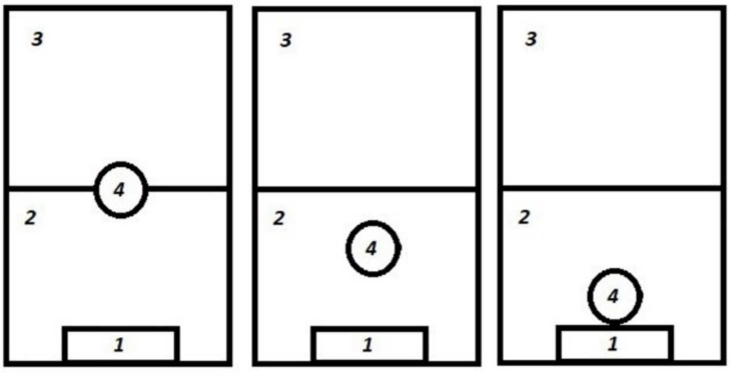

Fig. 4 The positions of a steel tea ball and a table tennis ball inside it at three different moments during free fall.

This experiment effectively illustrated that in a weightlessness, as experienced in laboratory conditions during free fall over shorter distances, the buoyant force that typically results from the presence of a gravitational field ceases to exist. Nonetheless, in the absence of a gravitational field, the magnetic effect continues to manifest during free fall.

3.1. Participants

In the seventh grade, there were two groups of participants representing two different classes. One class served as the control group Primary Scholl Control (PSC) with 26 students, where the teacher conducted lessons using a standard teaching approach, which will be described later in the text. The other class represented the experimental group Primary School Experimental (PSE) with 25 students, where one of the authors of the study implemented a different teaching approach from the norm, similar to those described in teacher's guidebooks with detailed lesson plans, which will also be explained in more detail in the text. A similar setup was employed with high school students, aged 15-16. One class served as the control group High Scholl Control (HSC) with 22 students, where lessons were conducted in the usual manner, while in the other class, a different class scenario with a certain degree of innovation was applied in experimental group High School Experimental (HSE) with 26 students.

The difference in teaching between the seventh-grade in elementary school and the first year of high school lies in the fact that in the first year of high school, the same teacher conducted lessons in both groups (and he is one of the authors of the study). However, in the seventh grade of elementary school, in PSC group, the lessons were taught by the teacher who typically teaches in both classes (she is also one of the authors), while in PSE group, the teaching was delegated to one of the authors of the study, who doesn't normally teach physics to these students.

3.2. Teaching Approach in PSC group

Although traditional lecture-based teaching is not extensively implemented in schools in Serbia, the teaching approaches implemented in the control groups will be referred to as the conventional teaching approach, while the teaching approach in the experimental groups will be called the innovative teaching approach.

The conventional teaching approach implemented by the seventh-grade physics teacher consisted of several sequences. The sequence of the class conducted in the control group in the seventh grade included the following tasks (the text is extracted from the teacher's written lesson plan):

"On the blackboard, there is a hammer with a drawing of the Leaning Tower of Pisa and attached squares of paper with experiments, questions, and tasks. By solving these, students return the papers to the teacher. This way, a poster about free fall is created.

Within their respective groups, students go through the following activities:

Experiments - To demonstrate that:

Heavier objects fall faster.

Objects of the same weight (different shapes) fall differently.

Objects of different weights fall the same.

Objects of different weights but the same shape fall the same.

When objects are in free fall, they "lose" their weight.

Each group conducts and presents its experiment that supports a given hypothesis.

Questions - Each group briefly answers one of the following questions:

What did Galileo prove with his experiment?

What is the purpose of a Newtonian tube?

What is free fall? How do we calculate the velocity and distance during free fall?

How is the weight of an object defined, how is it measured, and how is it calculated? Is the weight of an object the same everywhere?

The difference between gravitational force and weight, weightlessness.

Each group displays their paper with a brief response on the blackboard and presents their findings.

Task: Each group works on one item from the task:

On the internet, you can find information: The height of the Leaning Tower of Pisa, from the ground to the lower side, is 55.86 meters, and from the ground to the upper side is 56.7 meters. Is the following task correctly set up? If a 5-kg mass is released from the terrace of the Leaning Tower of Pisa and falls freely for 3 seconds:

What is the height of that terrace?

What is the velocity of the object at the moment of impact with the ground?

Draw a graph of the object's velocity.

What is the weight of the object?

What would be the weight of that object on the Moon (g = 1.6 m/s)?

Each group displays their paper with a solution to part of the task on the blackboard and presents it."

After students created a poster about free fall, the concept of weight was discussed through a frontal teaching approach. Subsequently, a demonstration was conducted for students, involving the fall of a container with an opening at the bottom, along with an explanation of why water does not flow out of the opening during free fall. The conclusion was drawn that water has no weight during free fall, meaning that there is no hydrostatic pressure. Following that, an experiment was shown in which a container with a magnet at the bottom was partially filled with water, with a floating tea ball containing a table tennis ball. Students observed that the tea ball was attracted to the bottom of the container by the magnet during free fall. The conclusion was made that the buoyant force ceased to act on the tea ball. Students recorded the experiments using their smartphones in slow-motion mode. Afterward, students were tasked with designing similar or entirely different experiments to investigate phenomena in a weightless environment, allowing them to showcase their creativity in experiment design.

3.3. Teaching Approach in HSC group

The teaching approach in the control group involved a demonstration of an experiment - the free fall of a container with an opening at the bottom, filled with water. Through this experiment, students were able to observe that water does not flow out through the opening during free fall, which typically happens when the container is at rest. Following that, the understanding of the concept of the relativity of weight was further supported by thought experiments involving an elevator moving upward, moving downward, and free fall. The content was reinforced with drawings. Students worked in groups on tasks involving specified accelerations of an elevator in which they had to explain the weight of a body in a given elevator motion scenario. Student groups presented their findings, and a common conclusion was drawn that in an elevator in free fall, a body will have no weight. (This example is present in physics textbooks and is used to define weightlessness as a state in which an object has no weight, while the textbooks omit information about the local disappearance of the gravitational field.)

The following sequence was repeated, as in the PSC group, by demonstrating weightlessness through an experiment involving the free fall of a container with an opening at the bottom, containing water and a floating tea ball with a table tennis ball. The observed phenomenon was discussed, a conclusion was drawn, and students were given the opportunity to design an experiment to study or prove a specific assumption about phenomena in free fall.

3.4. Teaching approach in both PSE and HSE

In the realm of science education, one effective method for fostering scientific thinking among students is the approach called 'Predict-Observe-Explain' (Haysom and Bowen, 2010). The applied teaching approach in the experimental groups was referred to as the Developing Critical and Creative Thinking Through the Predict-Observe-Explain Approach. This approach guides students through a structured process in which they begin by making predictions, followed by explaining their predictions, conducting experimental tests, and finally re-explaining the nature of the observed phenomenon.

The process begins with students formulating hypotheses—educated guesses—about the outcomes of an experiment or a scientific problem. This step encourages them to engage in critical thinking and apply their existing knowledge. Next, students engage in hands-on experimentation or research. This sequence involved a demonstration experiment that students recorded with their Android devices in slow-motion recording mode.

They gather data and observe the phenomenon in question, comparing their expectations with the real-world results. The core of the process lies in analyzing the results. Students are encouraged to explain the outcomes and understand the underlying principles. This step fosters a deeper understanding of the scientific concepts being explored. At the end of the process, students draw conclusions based on their findings. This stage enables them to reflect on the consistency of their initial hypotheses with the observed outcomes.

The Predict-Observe-Explain approach is a powerful tool for teachers who want to develop scientific thinking in their students. It encourages them to question, explore, and rationalize their understanding of natural phenomena. Moreover, it bridges the gap between theory and practice, as students see firsthand how their predictions align with reality.

By incorporating this approach into the physics classroom, the learning experience can be transformed. It stimulates critical thinking, problem-solving skills, and the development of a scientific mindset. The Predict-Observe-Explain method is not just about conducting experiments; it is about fostering curiosity, promoting logical reasoning, and cultivating the next generation of scientists and critical thinkers. Additionally, students were given extra tasks in which they had the opportunity to redesign experiments and specify which phenomenon they would investigate through those changes. They were also tasked with devising new experiments to further prove or verify what they had discovered in class.

The innovative teaching approach in the experimental group consisted of several sequences presented in two worksheets that provided instructions for individual student work.

Physics Worksheet 1

When we pour water into a stationary container with an opening at the bottom, water flows out through the opening. Explain the cause of this phenomenon.

What will happen if we allow the same container to fall freely? How do you explain your assumption?

Verify through an experiment what actually occurs.

When we allowed the same container filled with water to fall freely, the water stopped flowing. Explain this phenomenon.

When a container with an opening at the bottom is in a stationary position and sealed, with water up to a certain level, what will happen to the water? Explain your assumption.

Confirm through an experiment what happens to the water.

When a container with an opening at the bottom is stationary and sealed, the water inside the container will not keep flowing indefinitely; it will stop at some point. Explain this phenomenon.

How can you make the water flow through the container's opening again?

To make the water flow again, it is enough to press the container or unscrew the cap. Explain this phenomenon.

What will happen if we release a sealed container with an opening at the bottom containing water to fall freely? Explain your assumption.

Verify through an experiment what happens during the free fall of the sealed container with an opening at the bottom, containing water. Explain the observed phenomenon.

Physics Worksheet 2

A table tennis ball is placed inside a tea infuser ball. Water is poured into a container up to a certain level. A magnet is attached to the bottom of the container. The tea infuser ball floats on the surface of the water. The container is stationary on the table. What forces are acting on the tea infuser ball?

What will happen to the tea infuser ball as the container freely falls? Explain why this would occur as you described.

Observe the experiment and describe the phenomenon you notice. How do you explain the phenomenon you observe as the container freely falls?

Identify the force that appears to vanish and the force that continues to act on the tea infuser ball during the free fall of the container.

You have the opportunity to modify the experiment. What would you change, and what would you investigate with such a modification?

Devise a different experiment to demonstrate the same concept shown in the class experiment.

(The third sequence involved a demonstration experiment that students recorded with their Android devices in slow-motion recording mode.)In the seventh grade, there were two groups of participants representing two different classes. One class served as the control group Primary Scholl Control (PSC) with 26 students, where the teacher conducted lessons using a standard teaching approach, which will be described later in the text.

4. CREATIVE THINKING

Although specific tests for measuring creativity in physics education are currently unavailable, creative tasks can serve as an acceptable substitute. We have chosen this approach because standardized creativity tests often require the generation of new ideas or solutions to specific problems. The Torrance Test of Creative Thinking (TTCT) is not typically used directly in the context of physics education. However, it can be effectively integrated into teaching methods to encourage creative thinking among students in this field. One significant method for introducing the TTCT or its principles into physics education involves presenting students with challenging creative experiments (Kim, 2017). Within this framework, instructors can inspire students to design experiments or innovative variations of existing experiments that demand creative thinking and novel investigative methods—a concept seamlessly integrated into our teaching approach. By assigning complex creative tasks, we encouraged students to propose fresh ideas and solutions, which subsequently served as indicators of their creative development during their physics education. This approach facilitates the assessment of students' capacity to apply creative thinking and generate original ideas within specific physics contexts. Through a comprehensive evaluation of these creative tasks, we can gain a deeper understanding of the evolution of students' creative thinking.

Productive creativity, often referred to as "applied creativity," embodies the concept of harnessing one's creative skills to produce concrete and valuable outcomes. It represents the synergy between creative ideation and practical execution. Here are some key points to understand about productive creativity.

To assess student responses, we introduced two categories - productive and reproductive creativity. These two categories, productive and reproductive creativity, are of significance for our pilot study as they are relevant to student responses. Reproductive creativity refers to the ability to reproduce or reinterpret creative ideas, concepts, or works that have already existed or been seen. This type of creativity does not involve creating entirely new or original ideas but is based on the reinterpretation or recreation of existing elements. Students' performance on creative tasks serves as a direct indicator of their productive creativity. By evaluating the quality and originality of their ideas and solutions, we assessed their ability to apply creative thinking to challenges related to weightlessness.

5. Results and Discussion

During our pilot study, a significant number of responses in the Predict lesson sequences were identified, as well as changes in these responses following the Observe lesson sequences. However, it is crucial to underscore that this paper is devoted to accentuating the creativity exhibited by the students, which was instigated by the applied experiments. Consequently, in this study, we offer an overview of responses pertaining to the modified experimental design or the design of new experiments by the students. In Table 1-4, the responses of students from the 7th grade of primary school and the 1st grade of high school are presented. The responses are numbered so that the first two digit indicates the level of school (PS or HS), the letters E and C indicate whether the response is from the experimental or control group, and the number following the letter represents the sequential order of the response within the respective group. While specific tests for measuring creativity in physics education are not available, it is possible to use creative tasks as a substitute. We employed this approach because standardized creativity tests often involve tasks that require the generation of new ideas or solutions to specific problems.

The qualitative content analysis of responses from the participants in the PSE group provides valuable insights into their approach to productive creativity in experimental settings.

One prominent pattern in the participants' thinking is the exploration of different materials and fluids within the container. Their suggestions of using various combinations of materials, including ping-pong balls, metals, magnets, and different fluids such as alcohol and soap, exemplify their willingness to experiment with diverse elements. This approach reflects their desire to comprehend how alterations in materials can impact the behavior of the ball under weightless conditions. This open-mindedness and eagerness to explore various material possibilities showcase their productive creativity.

Another interesting pattern is the manipulation of magnets, which plays a central role in many responses. Participants experiment with the placement of magnets within the container or on the lid, indicating a curiosity about the magnetic field's influence on the ball's behavior during free fall. This experimentation with magnetic components reveals their innovative thinking in exploring the effects of external forces.

Table 1 The responses of students from the PSE

No	Responses
PSE1	▪ Attach one end of a string to the bottom of the container. Attach a ping pong ball to the other end of the string. When the container is filled with liquid, the ball floats on the surface. I think that in weightlessness, the ball would fall to the bottom of the container. We could use a liquid with higher density than water, such as mercury.
PSE2	▪ Place a magnet at the bottom of the container and fill it with water. Submerge a hollow ball containing several nails in the water (the ball floats when the container is at rest, but in weightlessness, it falls to the bottom).
PSE3	▪ Affix a magnet to the bottom of the container. Pour liquid soap into the container and place a hollow steel ball in the liquid soap.
PSE4	▪ I would pour alcohol into the container. I would insert a pencil with a metal part into the alcohol. I would investigate whether the pencil would sink to the bottom of the container.
PSE5	▪ I would secure a magnet to the container lid. The container would be filled with water, and a hollow metal ball containing a ping pong ball would float on the water. I am curious to know if the ball would remain on the water's surface during free fall.
PSE6	▪ I would place a magnetic rod at the bottom of the container with its north pole facing upwards. I would attach an elastic band to the container lid and place a magnet with its south pole facing downwards. The container would be filled with water so that the upper magnet is submerged. I would observe the behavior of the magnets when the container is in free fall.
PSE7	▪ The magnet is attached to the container lid. At the bottom of the container is a metal tea ball. I would let the container free fall to see if the metal tea ball would be attracted to the magnet. Then, I would repeat this with water in the container.
PSE8	▪ I would test if a metal ball, when it falls to the magnet during free fall, bounces.
PSE9	▪ If we place the magnet on the container lid and lower a tea ball containing a ping pong ball onto the water, it will float. But if we let the whole container free fall, the tea ball will jump to the magnet.
PSE10	▪ I would throw the container upwards and observe what happens while it goes up and when it starts to fall.
PSE11	▪ I would investigate what happens with balls made of different materials.
PSE12	▪ I would examine what happens in different liquids.

Table 2 The responses of students from the PSC

No	Responses
PSC1	▪ I would change the position of the magnet at the bottom of the container (place the magnet in the right corner) and observe if the ball would deviate toward the magnet during free fall.
PSC2	▪ I would use containers of different sizes and test if the ball always falls to the magnet.
PSC1	▪ I would change the position of the magnet at the bottom of the container (place the magnet in the right corner) and observe if the ball would deviate toward the magnet during free fall.
PSC2	▪ I would use containers of different sizes and test if the ball always falls to the magnet.

Table 3 The responses of students from the HSE

No	Responses
HSE1	▪ I would tie the ball to an elastic cord. I'd attach the cord to the lid. Then, I'd watch what happens to the ball while the container is falling.
HSE2	▪ I would change the position of the magnet. I'd place the magnet on the lid. I'd check if the ball would move towards the magnet as the container falls freely.
HSE3	▪ Instead of just letting the container fall, I would perform a bottle flip and study what happened from a slow-motion recording.
HSE4	▪ I would change the fluid to see if the ball still falls towards the magnet.
HSE5	▪ I would check if an ice cube placed in the container would sink to the bottom during the container's fall.
HSE6	▪ I would attach one magnet to the bottom, for example, with the north pole. For the other magnet, I would tie a balloon and place it in the water so that it faces the north pole at the bottom. As the container falls, the magnet will descend to the other magnet.
HSE7	▪ I would use a plastic ball. I'd throw the container upwards and observe which way the ball goes.
HSE8	▪ I would tie an inflated balloon to a metal ball. I'd observe whether the ball would move towards the magnet as the container falls.
HSE9	▪ I would do everything the same, but the container wouldn't have a lid. Then the water would spill out, and the ball would remain.
HSE10	▪ I would turn the apparatus upside down and then throw it upwards. I would study the phenomenon with a slow-motion recording.
HSE11	▪ I would place a magnet on both the bottom and the lid of the container. I would investigate whether the ball would move up, down, or stay in place.
HSE12	▪ I would change the experiment so that the container stands horizontally and check whether the ball would move towards the magnet as it falls or not.

Table 4 The responses of students from the HSC

No	Responses
HSC1	▪ I would take a larger container with more water, a stronger magnet, and a larger ball.
HSC2	▪ I would place a magnet on the lid of the container and then check if the ball would move upward while the container is falling.
HSC3	▪ I would change the fluid, using a denser one, and check if the ball still falls to the bottom.
HSC4	▪ I would use a larger apparatus but keep the same ball. I would check if the ball still falls to the bottom in this case.
HSC5	▪ I would make everything twice as large, including a magnet that is twice as strong, and then see if everything behaves the same as in the original experiment.
HSC6	▪ Instead of a magnet, I would use a chain that I'd attach to the bottom of the container. At the other end of the chain, I'd attach a ball. I would check if the ball falls toward the bottom as if the chain were pulling it.
HSC7	▪ I would take three objects, one of which floats, one that suspends in water, and one at the bottom of the container. I would release the container to fall and see what happens to each of the three objects

Furthermore, participants exhibit a proclivity for incorporating additional components like elastic bands, hollow spheres containing ping-pong balls, and steel balls. This inclination toward expanding the scope of their experiments demonstrates their creative mindset, as they seek to incorporate new elements to enhance their experiments and uncover new insights.

A key aspect of the participants' approach is their eagerness to observe the behavior of the components during free fall. This reflects their commitment to gaining a deeper understanding of the phenomenon in weightlessness. By allowing the container to free-fall, they demonstrate a proactive and hands-on approach to experimentation, which is fundamental to productive creativity.

The consideration of interactions between different components, such as magnets and balls, stands out in some responses. This suggests an acknowledgment of the complexity of the experiment, emphasizing their readiness to delve into intricate relationships between elements and their potential impact on the experiment's outcomes. This analytical and holistic approach to their experiments is a hallmark of productive creativity.

Additionally, participants propose variations in experimental conditions, including using fluids of varying densities, adjusting magnet polarities, and changing the container while it is in motion. These suggestions illustrate their interest in exploring how changing conditions can influence the experiment's results. It demonstrates a dynamic and adaptable approach to experimentation, showcasing their desire to uncover new insights through variations and adjustments.

In summary, the patterns observed in the responses of the experimental group participants reveal a strong inclination towards productive creativity. Their openness to experimenting with a wide range of components, materials, and conditions, as well as their consideration of interactions and willingness to adapt, underscores their innovative and exploratory mindset. These traits are essential for gaining a deeper understanding of the phenomenon of buoyant force disappearance in weightless conditions and represent a significant aspect of productive creativity in experimental research.

The qualitative content analysis of responses from the participants in the control group, as observed in the PSC group, reveals certain patterns that are characteristic of reproductive creativity:

- Changing the Position of Magnets: The predominant theme in responses from the control group is the suggestion to alter the position of magnets inside the container or at the bottom of the container. Participants express a keen interest in how manipulating the magnet's placement might influence the behavior of the ball during free fall. This pattern demonstrates their inclination to experiment with different experimental conditions, particularly regarding the magnetic field, to comprehend how such changes could affect the ball's behavior.
- Using Different Sizes of Containers: Some participants in the control group propose the utilization of containers of varying sizes to investigate whether the ball consistently falls toward the magnet. This suggests their curiosity about how alterations in the dimensions of the container might impact the outcomes of the experiment.

The identified patterns in the responses of the control group participants underscore their focus on changing specific experimental conditions, especially with regard to the magnet's placement and the dimensions of the container. However, it is notable that their responses often lack a deeper exploration of the underlying principles of physics at play. In contrast to the responses of the experimental group, which exhibited greater creativity in exploring alternative approaches and seeking a more profound understanding of the phenomenon, the control group appears to lean more towards a reproductive style of creativity. Reproductive creativity involves making incremental changes to established processes or conditions without delving into entirely new avenues of exploration.

The responses of the control group, as indicated by the identified patterns, seem to be characterized by reproductive creativity, focusing on minor variations in experimental conditions. While this approach is valuable for refining and optimizing existing knowledge, it may not lead to the same depth of understanding and innovative solutions as the more exploratory and creative approach demonstrated by the experimental group.

Based on the qualitative content analysis of responses from the HSE group, several common patterns in their creative thinking can be observed:

- Experimentation with Components: Most responses involve experimenting with various components, such as magnets, liquids, balls, or adding new elements like ice or balloons. This pattern shows the participants' inclination to explore different factors that could affect the behavior of the ball in weightless conditions.
- Challenging Traditional Approaches: Participants often suggest alternative approaches to the traditional experiment. For example, ideas like "bottle flip" or turning the apparatus emphasize a desire for innovation and experimenting with different techniques for studying the phenomenon.
- Changing Materials and Techniques: Some participants propose changing materials, such as replacing a metal ball with a plastic one, or experimenting with techniques, such as using slow-motion footage. These patterns indicate a consideration of the diversity of experimental conditions.

- Exploring Interactions and Complexity: Some responses delve into complex interactions between different factors, such as using two magnets or a combination of balloons and balls. This demonstrates an understanding that phenomena often arise as a result of complex factors.
- Examining Environmental Changes: These patterns reflect an interest in changing the experiment's environment, such as removing the container's lid or placing the container horizontally. This suggests that participants recognize the significance of the environment in which the experiment is conducted.
- Innovative Approaches: Ideas like adding ice or using inflated balloons introduce innovative elements into the research and highlight creativity in the participants' thinking.

All these common patterns suggest that participants demonstrate creativity in thinking about experiments and are inclined to explore different approaches to better understand the phenomenon of the disappearance of buoyant force in weightless conditions. These patterns also indicate the participants' ability to think outside conventional frameworks and experiment with different variables to expand their understanding.

The responses from the control group, as identified in the qualitative content analysis of the HSC group, exhibit a clear pattern of what can be described as reproductive creativity. Reproductive creativity involves making incremental changes to established processes or conditions without venturing into entirely new or innovative directions.

One prominent pattern is the Variation of Components in their responses. Participants in the control group often suggest altering different components of the experiment, such as the size of the container, magnet, or ball. This indicates a tendency to change experiment parameters to observe how modifications in these components might affect the results. While this demonstrates a willingness to experiment, it generally falls within the realm of traditional experimentation and incremental adjustments to known variables.

The suggestion to Scale Up the experiment is another indication of this reproductive creativity. Some participants propose increasing the size of various components, including the amount of water, magnet strength, and ball size. This shows an interest in exploring the impact of scaling up on the experiment's outcomes, but it remains within the scope of the original experiment's framework.

Changing the Fluid inside the container is another common theme among control group responses. Ideas about using denser fluids highlight their inclination to explore how different environments might influence the behavior of the ball. This is a subtle variation from the original setup but still within the realm of conventional experimentation.

Participants frequently propose Comparisons with the Original Experiment, indicating a desire to understand how alterations in parameters affect the experiment's results. This aligns with the idea of incremental change and the replication of known experiments rather than pursuing entirely new avenues of exploration.

A preference for a Simple Mechanical Approach is evident in some responses, where participants suggest using chains instead of magnets or considering the behavior of different objects during a fall. This preference for straightforward mechanical changes is consistent with a desire for incremental modifications.

While there is an acknowledgment of the complexity of the experiment and Exploring Interactions among Objects, these explorations tend to remain rooted in known physics principles, and the interactions are largely within the expected realm of possibilities.

Furthermore, the proposal to Compare Different Conditions is a common thread, with participants intending to assess how different objects behave under varying circumstances. This reflects an intention to explore differences in behavior but typically within the established boundaries of the experiment.

In summary, the responses from the control group illustrate a form of creativity that can be characterized as reproductive. They focus on variations within the existing framework of the experiment, incremental changes to parameters, and comparisons with the original experiment.

This differs from the responses of the experimental group, which were more creative in exploring alternative approaches and understanding the phenomenon.

The presence of productive creativity and similarities and differences in approach between the PSE and HSE groups is evident. First, it's evident that both groups share a Common Pattern of Experimentation with various components in their responses. They are open to exploring the effects of different materials, fluids, and additional elements on the behavior of objects in a weightless environment. This shared inclination to experiment with various factors demonstrates their creativity and the desire to gain a deeper understanding of the phenomenon. Furthermore, Interest in Interactions between Components is a common trait in both groups. They recognize the complexity of the experiment and understand how interactions between components, such as magnets and balls, can influence the behavior of objects. This demonstrates their willingness to explore different approaches and consider the multifaceted nature of the experiment. The key differences between the PSE and HSE groups are also worth discussing. One noticeable distinction is the Deeper Understanding of Physical Concepts among the high school students in the HSE group. They propose more complex and innovative ideas compared to the PSE group, challenging traditional approaches and suggesting experiments like "bottle flip" and slow-motion recording. This reflects a more advanced and creative approach to the experiment, showcasing their deeper grasp of physical principles. The HSE group also exhibits a Greater Awareness of Environmental Changes within the experiment. They consider modifications such as removing the container's lid or changing the container's orientation, indicating their deeper comprehension of how the environment can affect the experiment's outcomes. This demonstrates a more sophisticated understanding of the experiment's intricacies. In addition, the HSE group introduces More Innovative Elements into their experiments, such as adding ice or using inflated balloons. These ideas reflect a higher level of creativity and a willingness to explore unconventional methods, highlighting their advanced creative thinking. Overall, both the PSE and HSE groups demonstrate productive creativity through their experimentation with different components, recognition of interactions, and exploration of various experimental approaches. However, the high school students in the HSE group exhibit a deeper understanding of physical concepts and a more advanced level of creativity in their approach, evident in their innovative ideas and the consideration of the experiment's environment. This illustrates how education and knowledge level can influence the depth and sophistication of creative thinking in scientific experiments.

6. Conclusion and Further Research

The results of our research indicate positive implications for the improvement of physics education through the implementation of new experiments and an innovative teaching approach. We would like to highlight several key implications:

- New experiments and approaches promote productive creative thinking among students. Our analysis of responses from the experimental group clearly demonstrates that they have become capable of designing and conducting experiments in innovative ways. This is a crucial skill that is not only valuable in physics but also in the broader context of education.
- Connecting with the Real World: Our experiments simulate the conditions of weightlessness, which is essential for connecting physics with the real world and applying scientific principles beyond the classroom. This contributes to students' understanding of physical laws and motivates them to study physics.
- Our research approach and the use of creative experiments represent innovations in the field of education. It can serve as a model for future innovations in teaching and empower teachers to experiment with their approaches.
- In the broader context of education in Serbia, our research can serve as an example of how to enhance the quality of teaching and stimulate creative thinking among students. Furthermore, our research highlights the importance of adapting teaching methods and content to better reflect the realities and needs of today's students. These insights and experiences can inspire other educators and educational institutions to explore new approaches to learning and teaching.

The questions that the students answered were of an open-ended nature. Individual work with students in the experimental groups was conducted to collect responses during the course of the 'Observe' sequence, in order to create a list of provided answers for future, more comprehensive research. We find this approach justifiable, considering that this is a pilot study with a limited sample size, although we are fully aware of the benefits of participant interaction in pair or group settings, facilitating the explanation and exchange of ideas (Crouch at al., 2004).

References

Crouch, C., Fagen, A., Callan, P., & Mazur, E. (2004). Classroom demonstrations: Learning tools or entertainment? American Journal of Physics, 72(6), 835. doi:10.1119/1.1737259

Haysom, J., & Bowen, M. (2010). Predict, observe, explain: Activities enhancing scientific understanding. NSTA Press.

Kim, K. H. (2017). The Torrance Tests of Creative Thinking - Figural or Verbal: Which One Should We Use? Creativity. Theories – Research - Applications, 4(2), 302–321. doi:10.1515/ctra-2017-0015

Krulj, I. M., & Sliško, J. (2023). Absence of buoyant force in free fall: A magnetic demonstration. The Physics Teacher, 61(4), 312-313. doi:10.1119/10.0005482

Hobson, M. P., Efstathiou, G., & Lasenby, A. N. (2006). General Relativity: An Introduction for Physicists. Cambridge University Press.

Haym Kruglak, (1963). "Apparatus for Teaching Physics: Physical effects of apparent 'weightlessness'", The Physics Teacher 1, 34.

Sliško, J. (2020). A new role for the Cartesian diver: Showing freefall weightlessness. Phys. Teach., 58, 446. doi:10.1119/1.5144427

Sliško, J., & del Rosal Garduno, R. (2022). A bubble-based demonstration of free-fall weightlessness. Phys. Teach., 60, 248. doi:10.1119/10.0006426

Sliško, J., Topalović, T. M., & Božić, M. (2021). The Physical Cause of Atmospheric Pressure: Weight of Air or Molecular Motion and Impacts? The Physics Teacher, 59(6), 470-473. doi:10.1119/10.0004094

PODSTICANJE KREATIVNOG RAZMIŠLJANJA KOD UČENIKA U OSNOVNOM I SREDNJEM OBRAZOVANJU PUTEM JEDNOSTAVNIH EKSPERIMENATA ZASNOVANIH NA AJNŠTAJNOVOM PRINCIPU EKVIVALENCIJE

Iste nastavne jedinice o Gravitaciji i bestežinskom stanju bile su realizovane na različite načine-tradicionalnim pristupom koji ne podrazumeva isključivo predavanje nastavnika, ali se već dugo primenjuje u praksi kombinacijom različitih nastavnih metoda, i novom primenom pristupa Predvidi-Posmatraj-Objasni uz realizaciju dva nova eksperimenta dizajnirana za inoviranje nastave fizike. Cilj pilot istraživanja bio je provera podsticaja kreativnog mišljenja učenika i to u sedmom razredu osnovne škole i prvom razredu srednje škole. Pokazano je da su učenici koji su pratili inoviranu nastavu pokazali veći stepen kreativnosti.

Ključne reči: *bestežinsko stanje, školski eksperiment, nastavni pristup predvidi-posmatraj-objasni, kreativno mišljenje*