Active learning of buoyancy: an effective way to change students’ alternative conceptions about floating and sinking

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Abstract. We present research into the effects of traditional teaching and an applied active learning model to overcome students’ alternative conceptions on floating and sinking with a sample of 153 thirteen-year-old students in Serbia. An overview of the most important properties of the experimental model of active learning based on the IBSE approach is given. The results show significant differences in achievements between the control and the experimental group: the average normalized gain was 0.84±0.21 for experimental group and 0.04±0.25 for the control group, which points to the need for adoption of modern constructivist view on learning within the teaching process.

1. Introduction
According to the latest available PISA report, 35% of Serbian students did not achieve the level of functional literacy in science [1]. Poor achievements by students in all domains (science, mathematics, literacy and problem-solving) indicate that the educational system in Serbia is still focused on acquiring and valuing knowledge on the reproduction level. There is a clear need for an organized series of activities aimed at improving everyday teaching practice. This includes research-based design of teaching strategies.

This paper presents some results from a wider research project aimed at investigating the effects of traditional teaching and the application of active learning methods to overcome students’ alternative conceptions on floating and sinking. One of the main goals of this project was to point out and problematize the phenomenon of students’ alternative conceptions when physics teaching and learning is concerned, since there were practically no investigations done on this topic in Serbia.

Additionally, keeping in mind that providing scientific explanations for events and processes in nature is one of the key elements of scientific literacy, it was necessary to point out the importance of acknowledging the existence of students’ alternative conceptions, the applications of proper methods for their identification and adequate teaching strategies aimed at overcoming them.
2. Problem
Although floating and sinking are everyday phenomena frequently experienced by students, research shows that they represent a highly demanding teaching subject [2–5]. One of the key problems encountered by students while adopting the proper scientific explanation of floating and sinking, is proper understanding of the concept of density and the impact the relationship between the densities of objects and fluids has on these phenomena. While density may seem to be an intuitively clear concept, research has shown that this is not the case [6–7]. It is a derived physical quantity representing the relation between mass and volume of an object. However, everyday life offers few situations in which the mass or volume of a physical body can be independently varied, and, consequently, students tend to base their concepts of density on only one of the physical quantities it is derived from [8].

On a similar note, when dealing with the topic of floating and sinking, students are required to accept an explanation more complex than a simple causal relation. The behavior of an object immersed into a fluid depends on the absence or presence of balance between the forces acting on it (gravitational and buoyant force), which forces students into adopting a new, more complex model of causal understanding.

Overcoming students’ alternative conceptions on those phenomena requires an application of appropriate teaching strategies based on active learning methods [2–5], which poses a great challenge for an educational system dominated by a traditional, lecture-based approach to teaching, in which the central role is reserved for a teacher and students are mostly asked to simply reproduce knowledge.

3. Methodology of research
3.1. Sample and procedure
The research was conducted with a sample of 153 seventh-grade primary school students (13 years old) in Užice (Serbia). These students were introduced to the concept of density during the previous year, through traditional physics lessons, but did not learn about buoyancy yet.

The research was designed as a pedagogical experiment with two parallel groups that acquired knowledge on buoyancy and related phenomena during a three-week period. Students of two primary schools from the Užice region took part in the experiment. The two schools were treated as one entity for the purpose of selecting students for experimental and control groups. The classes that were used in forming the groups were randomly chosen from the common sample of all the classes in the two schools. The control group comprised 79 students, and the experimental group had 74 students.

The two groups of students were equalized in terms of cognitive development levels, as measured by the BLOT test [9], and by academic achievements, expressed by their physics grades and overall midterm grades. There was no statistically significant difference between the two groups on the initial diagnostic test that was checking for the presence of alternative conceptions on floating and sinking. This test was created by modifying the original Diagnostic Test [4], which was applied as both initial and final test in this research.

Teaching on buoyancy and related phenomena was implemented in six classroom sessions. During the first five, different models of teaching were applied in the control and the experimental group. The final, sixth, session, was implemented so that the students from both groups took part in equal activities, with the aim of comparing their achievements in the application of knowledge on non-classical tasks on buoyancy and related phenomena (a critical analysis of a solved numerical problem and an interpretation of a video showing some unusual physical occurrences).

The students in the control group had been taught by a traditional lecturing method, based on verbal transmission of knowledge, classroom demonstrations and numerical problem solving. Students typically did not ask any questions during lectures, nor were there discussions about unclear points. Students in the experimental group were involved in active physics learning consisting of: a) introduction of new concepts through the learning cycle phases: exploration, concept introduction, concept application; b) various experiments implemented during all learning phases; c) a Predict-Observe-Explain learning activity for the enhancement and application of knowledge; d) application of
investigative homework; and e) discussing physical problems in small peer groups during different learning stages. This teaching design is characterized by the introduction of new concepts through investigations and application of knowledge in different situations, with strong encouragement of peer interaction and freedom of expression. Students are given tasks that make them combine their knowledge and emphasize the use of critical thinking skills. Allowing students to make mistakes and then learn by correcting them is of vital importance.

3.2. Instruments
The effects of different learning experiences on overcoming students’ alternative conceptions on floating and sinking were measured by examining gains on the Modified Diagnostic Test that was implemented both before and after the learning sequence on buoyancy.

The original Diagnostic Test for detection of presence of alternative conceptions related to floating and sinking was developed by Yin and associates [4]. Analysis of existing literature on the subject and detailed studies led them to single out the 10 most common alternative conceptions students have on floating and sinking: 1) big/heavy objects sink, small/light objects float; 2) objects which contain air float; 3) objects with holes sink; 4) flat objects float; 5) sharp edges make object sink; 6) vertical objects sink, horizontal objects float; 7) hard objects sink, soft objects float; 8) filling heavy objects with floating materials makes them float; 9) large amount of water makes objects float; 10) sticky liquid makes objects float. The original test consists of 10 questions with illustrations, each related to one of the above-listed alternative conceptions. Each question first states the behavior of one object when placed in water, and then asks students to predict if a different, yet in some respect similar, object will float or sink.

For the purposes of this research modification of the original Diagnostic Test [4] was an addition of the request to provide detailed justifications for each of the answers, which led to a different scoring system than the one used in the original test. Selecting an answer (floats or sinks) and giving a justification were viewed as a single item. Possible categories of students’ answers were:

- Scientific conception/explanation (correct answer with proper explanation, including stating the relation between the densities of object and fluid and/or gravitational an buoyant force as the cause of floating/sinking);
- Alternative conception/explanation (wrong answer with an explanation that clearly points to a presence of an alternative conception);
- Wrong answer (answered with a wrong explanation that is not an alternative conception, or an answer with an explanation pointing to student misunderstanding the question);
- Answers without explanation (one of two answers were chosen but no explanation was provided).

The students’ answers to the questions on the Diagnostic Test were graded independently by two investigators and a high degree of agreement was reached (98%).

In order to better compare the differences in students’ achievements on the final and the initial test, each category of students’ answers was assigned a numerical value between 0 and 3: answers without explanation–0, wrong answers–1, alternative conceptions–2, and scientific explanations–3. Additionally, when calculating the normalized gain, the value 0 was assigned to answers belonging to one of the first three categories (answers without explanation, wrong answers and alternative conceptions) and the value 1 to the fourth category, scientific explanations. This enabled the determination of the gain achieved on the Diagnostic Test, compared to the possible gain regarding the degree of adoption of scientific concepts on floating and sinking [10].

3.3. Data analysis
Descriptive statistical measures (frequencies and percentages of students’ answers) for determination of the degree of presence of scientific and alternative conceptions on floating and sinking were used when comparing the attainment of the control and experimental groups. Variance analysis of the difference in scores on the final and the initial test and of the normalized gain in the control and the experimental group was used to determine the progress on the final diagnostic test compared to the initial one.
4. The most significant properties of the experimental model for teaching about buoyancy

An inquiry-based science education (IBSE) approach [11] was selected as the basis for the experimental teaching model. Some notable properties of the implemented teaching model are:

- Plan the lessons as a single unit so that the students would participate in the key stages of the learning cycle – the investigative stage, concept introduction and the application of concepts to different situations [12];
- Create opportunities for the adoption of novel concepts through active participation in different stages of investigation: problem definition, hypothesis formulation and testing through practical activities, reaching and evaluating the conclusions;
- Encourage the activation of students’ previous knowledge, with exposed alternative conceptions serving as basis for the construction of scientific concepts;
- Cause cognitive conflict, i.e. create situations where students are faced with the limitations of their alternative conceptions, by encouraging small-group discussions and demonstrating different phenomena through Predict-Observe-Explain activities [13];
- Encourage peer interaction [14] in different learning stages, from investigation and introduction of new concepts to applications of those concepts in different scenarios;
- Permanent interaction between students and the teacher – exchange of adequate and timely feedback to direct students throughout the learning process and provide the teacher with an opportunity to lead the teaching process in an efficient manner, aimed at active construction of knowledge;
- Tasks given to students in different stages of the learning cycle are diverse and include numerous practical activities that enable direct interaction with environment as well as varied conceptual and numerical problems of different complexity;
- Homework assignments hold an important place in this model and serve multiple purposes, from verbalization of acquired knowledge, through activation of everyday experiences on the subject matter, development of skills needed to work with different sources of information, to encouragement of individual investigative efforts, abilities to present what was learned and the application of adopted concepts in different situations;
- The ways in which the tasks are presented lead naturally to individual or small-group activities, with the encouragement of self-regulated learning [15] and responsibility for personal learning progress.

Table 1 shows a brief overview of implemented activities during the regular physics classes and through homework assignments. Some teaching materials are available on the following website: https://radovanovicjelena.weebly.com/active-learning-of-buoyancy.html.

The described model has low demands on resources and is applicable even in very modest conditions, but implementing it in an exactly defined timeframe, significantly shorter than other investigations into the application of interactive teaching approaches to the problem of overcoming alternative conceptions on floating and sinking [2-3, 5], can be challenging.

| Section | Key student activities |
|---------|------------------------|
| **Lesson 1 and 2. Learning about the basic properties of buoyancy:** | - Investigative work in small groups about buoyancy acting on an object immersed in fluid and finding the way to determine its numerical value as the difference between the object’s weight in the air and in the fluid. |
| 1) When does buoyancy occur and how does it affect objects? | - Investigation into the properties of buoyancy (formulating and testing hypotheses, reaching conclusions on group level, |
| 2) How to determine the numerical value of buoyant force? | |
3) What affects the numerical value of buoyant force, and what does not? Presenting group results, generalization of conclusions at class level, providing mathematical formulation. - “Discovering” the Archimedes’ principle.

**First homework assignment.**
Basic concepts about buoyancy Generalization of knowledge on basic properties of buoyancy by answering a series of questions and solving simple numerical problems (individually).

**Lesson 3. Buoyant force and Archimedes’ principle:**
1) Demonstration of buoyancy in liquids through Predict-Observe-Explain activity
2) Demonstration of buoyancy in gasses
3) Practical verifications of Archimedes’ principle
- Participation in demonstration of buoyancy with water-filled balloon [16] by providing individual predictions and explanations and group discussions.
- Predicting and explaining the behavior of helium balloon in air at group level.
- Planning and implementing group-level activities to verify Archimedes’ principle: Determining buoyancy as a difference between object’s weights in air and in water; Measuring the mass of water displaced from a filled container after an object is immersed; Calculating the weight of the displaced water; comparing the values for buoyant force and the weight of the water and reaching conclusions.

**Second homework assignment**
On Archimedes Critical reading of a short text on Archimedes, discussion, answering questions about the text and group discussion, solving a numerical problem based on the legend about Archimedes and the crown.

**Lesson 4. Application of Archimedes’ principle; Floating and sinking:**
1) Determining object’s density by the use of Archimedes’ principle
2) Analysis of conditions leading to floating and sinking
- Practical activities of measuring, application of formulae and reaching conclusions with the use of a worksheet, additional questions and group tasks with the goal of determining object’s density through the use of Archimedes’ principle; Rough estimate of correctness of final density values by comparison with the water density.
- Group discussion on conditions leading to floating and sinking, presentation of group conclusions and discussion.

**Third homework assignment**
Investigative homework “Do apples sink in water?”[17] Individual planning, implementation and evaluation of an investigation into the way apples behave in water; Practical activities of determining an apple’s density; Formulating conclusions on conditions for floating and sinking; Making a presentation of the investigation and conclusions (ppt or doc format) and sending it via E-Mail.

**Lesson 5. Buoyancy and related phenomena:**
1) Analysis of the homework assignment on apples
2) Confronting the alternative conceptions about floating and sinking – evidence for and against
- Analysis of several selected homework assignments on apples and evaluating their quality using pre-defined criteria.
- Stating the evidence in favor and against claims made on conditions leading to floating and sinking noted during the previous lesson’s group activities with occasional practical tests; reaching final conclusions.

**Fourth homework assignment**
Reinforcing the knowledge on buoyancy and related phenomena Individual answers to the series of questions following the lesson in the textbook, with two additional text-related problems from the Curiosities section.
5. Results of the comparison between the effects of traditional teaching and of the active learning model

5.1. Achievements of the students in the control group and experimental group on the final diagnostic test

In order to compare the effects of traditional teaching with the effects of the active learning about buoyancy and related phenomena on overcoming alternative concepts and adopting scientific concepts about floating and sinking, frequencies and percentages of the students’ answers were calculated for each question on the final diagnostic test.

The achievements of the students in the experimental group could be considered high with regard to giving scientific explanations. Around 90% of the students in the experimental group provided scientific explanations on questions designed to check the presence of the following alternative conceptions: Large and heavy objects sink, small and light float (89.2%); Hollow objects sink (90.5%); Flat objects float (93.2%); Sharp edges make objects sink (93.2%); Object will sink in vertical position but float in horizontal position (94.6%) and Large quantities of water make objects float (87.8%). Around 80% of the students gave scientific explanations to the questions dealing with: Hard objects sink; soft objects float (79.7%); Adding floating material helps heavy objects float (77.0%) and Sticky liquid makes objects float (82.4%). The students in the experimental group had the lowest achievement levels on the question about Objects containing air always float, with only 70.3% of the students providing scientific explanation.

The achievements of the students in the control group were significantly lower. The best results in the control group were for the fourth and the seventh questions (Flat objects float and Hard objects sink; soft objects float), with around one third of the students (32.1%) giving scientific explanations. All other questions had the percentage of scientific explanations below 30%, and even below 10% on the first, third and eighth question (Large and heavy objects sink, small and light float; Hollow objects sink; Adding floating material helps heavy objects float). The differences between the experimental and the control group in the number of alternative conceptions present in the final diagnostic test are very notable. Very few of the students in the experimental group provided answers that point to the presence of alternative conceptions, from only 1.4% on the first, third, fifth and ninth questions (Large and heavy objects sink, small and light float; Hollow objects sink; Sharp edges make objects sink and Large quantities of water make objects float) up to 10.8% on the second and eighth questions (Objects that contain air always float and Adding floating material helps heavy objects float). In the control group, the least amount of alternative conceptions were related to the ninth question (Large quantities of water make objects float), 15.4%, and the most on the second one (Objects that contain air always float), 44.9%.

The number of answers without an explanation was high in the control group: between, approximately, one quarter up to one half of students, depending on the question, provided answers without any explanations. These answers were most frequent on the first and ninth questions (Large and heavy objects sink, small and light float and Large quantities of water make objects float), with 53.2% and 46.2%, respectively, with most of the students choosing the correct answer, but unable to provide any explanation. All other questions in the control group saw approximately equal distribution of correct and wrong answers to answers without explanations. On the other hand, few students from the experimental group failed to provide explanations with their answers (between 1.4% and 10.8%, depending on the question).

5.2. Control and experimental group students’ gain on the final diagnostic test

Comparing the achievements of the students in the control group on the initial and final diagnostic test (Figure 1), a rather modest gain of just a few percentage points can be seen with regard to the scientific explanations on the second, fourth, fifth and eighth questions (Objects that contain air always float; Flat objects float; Sharp edges make objects sink and Adding floating material helps heavy objects float), and a bit larger gain, of around 10 percentage points, on sixth, seventh, ninth and tenth question (Objects...
will sink in vertical position but float in horizontal position; Hard objects sink; soft objects float; Large quantities of water make objects float and Sticky liquid makes objects float). Additionally, a slight loss in the percentage of scientific explanations can be seen on the first and third questions (Large and heavy objects sink, small and light float and Hollow objects sink).

The control group demonstrates a moderate reduction in the percentage of students exhibiting alternative conceptions on most questions. The exception is question six (Object will sink in vertical position but float in horizontal position), where the percentage of students with alternative conceptions was halved, but also questions three and ten (Hollow objects sink and Sticky liquid makes objects float) with a small increase in the number of students with alternative conceptions, which should be studied further.

![Figure 1](image.png)

**Figure 1.** Percentage point change in control group students’ achievements between the initial and the final diagnostic test on floating and sinking.

The experimental group shows a clear and significant gain in the percentage of scientific explanations on all questions on the final diagnostic test compared to the initial test, and, at the same time, a reduced presence of all investigated alternative conceptions (Figure 2).
Figure 2. Percentage point change in experimental group students’ achievements between the initial and the final diagnostic test on floating and sinking.

The average difference in scores on the final and the initial diagnostic test is 10.5±4.55 for the experimental group and 0.4±4.5 for the control group. Variance analysis shows that this difference is statistically significant ($F(149,1) = 187.214; p<0.001$).

Looking at the normalized gain, it is noticeable that a whole of 72.7% of the students in the control group shows no progress in overcoming alternative conceptions on floating and sinking, whereas only 1.4% of the students from the experimental group failed to make progress on the final diagnostic test, compared to the initial test. On the other hand, 75.7% of the students in the experimental group achieved significant progress, compared to only 1.3% of the students from the control group (Table 2).

Table 2. Participation of different gain categories for control and experimental groups as measured between the initial and the final diagnostic test.

| Categories                  | Control group | Experimental group |
|-----------------------------|----------------|--------------------|
|                             | Number and percentage of students | Number and percentage of students |
| No gain (-1.00 – 0.09)      | 56 (72.7%)     | 1 (1.4%)           |
| Mild gain (0.10 – 0.29)     | 9 (11.7%)      | 2 (2.7%)           |
| Moderate gain (0.30 – 0.69) | 11 (14.3%)     | 15 (20.3%)         |
| Significant gain (0.70 – 1.00) | 1 (1.3%)    | 56 (75.7%)         |
With regard to the average value of normalized gain, there is a statistically significant difference between the control and the experimental group ($F(149,1)=440.822; p<0.001$). In the control group, the average normalized gain is $0.04\pm0.25$, and in the experimental group it is $0.84\pm0.21$.

It is clear that the experimental model of teaching aimed at active learning about buoyancy and related phenomena, as applied in this research, has significantly higher positive effect to overcoming students’ alternative conceptions about floating and sinking, compared to the traditional approach to teaching.

6. Conclusion
The results of this research clearly confirm the advantage of an interactive approach to teaching, compared to a traditional approach, which agrees with the findings of numerous international studies emphasising the need for application of interactive approaches to teaching [10–11, 14, 18], i.e. the importance of accepting constructivist views on learning in the teaching process [19]. These results point to the need for changes in primary education of teachers in Serbia, and to the importance of innovations in professional training programs for physics teachers by inclusion of elements pointing out the advantages that the interactive approach to teaching has over the traditional approach and providing pointers for concrete classroom activities aimed at identification and overcoming of students’ alternative conceptions.

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