

Investigative homework with apples: An opportunity for primary-school students to learn actively the relationship between density and flotation

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Abstract:

This paper describes investigative homework with apples, aiming to contribute to the primary-school students' understanding of density and conditions leading to floating and sinking. The assignment represents an opportunity for individual autonomous learning of physics and adoption of established scientific concepts through practical activities with easy-to-find objects. We describe the assignment and typical approaches taken by the students, followed by the detailed analysis of homework quality as a function of previous knowledge and mode of assignment (mandatory or voluntary). The research was performed on a sample of 46 primary-school students (7th grade) during preliminary testing of effects produced by active learning methods introduced into the teaching of buoyancy and related topics.

Keywords: investigative homework, active physics learning, floating and sinking, density, primary-school physics.

Introduction

Research on functions and effects of homework in academic learning has a long tradition. Many research studies have shown that homework has positive influence on students' academic achievements (Cooper et al., 2006). However, the influence is variable, owing to the fact that not all teachers assign homework, nor do all students complete their assignments. According to a review of research on homework assignments conducted between 1987 and 2003 (Cooper et al., 2006), some of the most significant aspects of homework are better retention of factual knowledge, increased understanding, better critical thinking, concept formation and information processing. Additionally, homework is shown to contribute to development of work discipline, better time organization, increased inquisitiveness and problem-solving autonomy in students. Assignments can also have positive effects on the student-parent-school relationships by increasing parents' interest in students' achievements and underlining the connection between school and family life.

On the other hand, studies have shown some of the possible negative effects: loss of interest in academic material, physical and emotional fatigue, pressure to complete homework and perform well, cheating, copying from other students and receiving help beyond tutoring. Therefore, continued studies are needed to provide teachers with clear guidelines on selection of homework types, length and frequency, degree of choice allowed for the student, degree of individualization, and social context.

As for the science classes, different kinds of investigative homework assignments have been shown to play a very important role (Newby and Winterbottom, 2011). For these activities to have any success, teachers should:

- (a) choose the research topic carefully so that it requires thought, rather than a “copy and paste” approach;
- (b) provide a variety of topics and presentation formats to engage as many of the students as possible;
- (c) describe the assessment criteria carefully, to ensure that students have a good understanding of what a successful piece of homework will look like;
- (d) leave enough time for analysis and discussion of solutions, with an option for the students to submit their final versions after that; and
- (e) train students in the use of self- and peer-assessment so that they evaluate the whole piece of work and do not just focus on obvious exclusions or errors.

Still, it is often difficult to motivate students into doing their homework, especially when they are of adolescent age, which demands constant perfection of homework types and modes of assignment by the teachers (White, 2002; Newby and Winterbottom 2011).

In this paper we will show one example of investigative science homework intended to help students adopt durable knowledge of conditions under which objects sink or float. This kind of assignment has significant advantages, compared to classical algebraic problems. One of these advantages is, for example, far greater interest shown by the students. The assignment does not require much time to complete, and does not infringe on the usual students' activities, while at the same time provides multiple benefits with regards to understanding phenomena related to density, floating and sinking.

Sinking and floating are common everyday phenomena. However, it is a conceptually challenging scientific subject. Students, required to adopt the scientific explanation of these phenomena, are faced with the two key problems: proper understanding of density and realization that the sink or float situation can be understood by analyzing the relationship between the average density of an object and the density of the liquid in which it is being immersed. Research has shown that dealing with the students' alternative conceptions is one of the more daunting tasks placed before any science teacher (Yin et al. 2008; Yin, 2012). However, applying well developed teaching strategies, in accordance with students' everyday experiences, contributes to the understanding of real causes behind floating or sinking (Gang, 1995).

It is well known that scientific concepts, inherently abstract due to their universality, can seem to be completely disconnected from everyday life, especially when taught to schoolchildren outside of context of their applicability (Fleer, 2009). The solution lies in application of inquiry-based learning. Inquiry teaching and learning is both hands-on and minds-on. It is hands-on because it involves pursuing experiments, manipulating materials, answering questions, and working cooperatively. It is minds-on because it requires active student thinking, problem solving, analysis of information, and making meaningful connections to everyday life (Benedis-Grab et al., 2009).

Although "doing" science actively is the only way for the students to master the scientific concepts, these methods often require a lot of classroom time to implement. Certain learning sequences should therefore be organized outside of classrooms, and those sequences should be adequately designed investigative assignments encouraging individual active learning of physics. Experiments performed by the students themselves, and the conclusions arrived at by doing so, have much greater educational value than learning facts from textbooks, encyclopedias and other written materials (Cvjetičanin et al., 2010).

Importance of experiments using simple and easily obtainable objects has been well established (Breckenridge and Zweuifel, 1993). The homework assignment we are about to describe requires

students to determine density of an apple and elaborate on its behavior when put in water. Floating or sinking of fruit can be surprising to students. That led some science textbook authors to recommend the use of “uncommon” properties of a lemon (floating when complete, but sinking when peeled) for demonstrations (Stančić, 2011). However, considering the importance of autonomous students’ experimentation, we would suggest the use of apples for autonomous active learning of density and conditions leading to floating or sinking.

The Assignment

The apple assignment was given to a total of 46 seventh grade students (13 years of age) of an elementary school in Uzice (Serbia), taught by the first author (Jelana Radovanovic). The students were divided into two equal groups, and the assignment was a part of the topic on Equilibrium, taught during the spring semester of 2012. Preliminary research was conducted, with the goal of designing a teaching strategy for the topic of buoyancy and related phenomena, based on active learning methods. The lectures were implemented using modified traditional approach, which included elements of active learning, primarily in methods dealing with testing the acquired knowledge.

After the topic of buoyancy and Archimedes’ principle was presented to them, the students were given worksheets, with an assignment to conduct their own little research at home, with the purpose of obtaining answers to the following questions and tasks:

- What is the mass of a typical apple?
- Find a way to determine the volume of an apple, and then find the volume of one typical apple.
- Use the mass and volume data to calculate the density of a typical apple.
- Will apples sink or float when placed in water?

The students were asked to describe, in detail, the flow of their research and any conclusions they have made, as well as to make photographs or video-recordings of the research, when possible. They were also given an opportunity to express their opinions on this type of homework assignment. The homework reports could be presented in many forms: written, printed and electronic – burned to a CD or as an e-mail sent to an address created specifically for this kind of activities.

We will now turn to describing the typical students’ activities as they were working on their assignments, with a selection of examples from students’ reports.

Students’ methods for finding mass and volume of an apple

Let us first analyze the methods they have used to determine the average mass and volume of an apple.

There are two dominant ways for determining the mass of a typical apple:

- A student picks up an apple which she or he considers to be a typical example and uses a kitchen scale to measure its mass:

“I went to the market and picked one apple that seemed ‘normal’ i.e. average to me. At home I used a kitchen scale to measure it. Its mass was 180 g.”

- A student measures several apples using a kitchen scale (individually or all together), and then divides the total mass by the number of apples and presents the result as an average mass of an apple:

“Using a small kitchen scale I have measured the total mass of the three apples I found in the kitchen, and then I divided that result by three. That value represents the average mass of a single apple, and it is equal to 150g.”

While this is a good way to find an average mass of an apple, most of the students using this method failed to clearly report which of the measured apples they used for the next part of their research, to determine a volume of an apple.



Figure 1. Example photographs from students' reports - measuring mass

For the purpose of finding out the volume, students' have used various approaches. Most of them have applied the method based on their knowledge on how to determine the volume of an irregular-shaped object by submerging it into a liquid.

Students that have noticed that their sample apple would float on water, thus rendering the resulting volume inaccurate, have used various items to keep the apple completely submerged. Some have used a thin wire, a toothpick, a tip of a knife, a teaspoon or, simply, a fingertip. They have all clearly understood that the item used had to be of a small volume itself, although only a few of the students have mentioned that explicitly in their reports. We will now quote several of the answers given by the students:

- One of the students wrote:

“I have placed an apple in a pot, and held it down with a knife that has negligible volume, because the apple tended to float. Volume of the water itself was 300 ml, and the volume of the water with the apple was 450 ml. That means that the volume of the apple itself is 150 ml = 150 cm³.”

- Another student gave a more detailed description:

“This experiment requires a substance of known volume (water). If the density of the sample is less than the density of water, it will float and has to be pushed down. To avoid errors, one could use less dense substance than water, such as an ethyl-alcohol (density 790 kg/m³). Fill a container with liquid (water), up to a certain level, making sure that it doesn't spill over when the sample is inserted. Then put an apple into the water. There was 0.5 l of water in the container. Now the water level is 0.65 l. Since the apple floats in water, one has to push it down with a thin stick, so that it sinks. The water level has risen again, and is now 0.7 l. Volume of the apple is 0.2 l.”

A different approach, found in fewer reports, is also inspired by knowledge that the volume of displaced liquid is equal to the volume of submerged body, but the volume is not calculated and is instead measured directly. Here is one such example:

- “Volume of a typical apple is 1.87 dl = 187 cm³. I have placed a pot full of water into another, larger, empty pot. I placed an apple into a water-filled pot and slightly pushed it down, using a tip of a knife, so that it would be submerged completely. Some of the water spilled over into a larger container. The volume of the water in the larger pot is equal to the volume of the submerged apple. I used the kitchen measuring cup to find out the volume of the water.”



Figure 2. Example photographs from students' reports - measuring volume

Several of the students have attempted to determine the volume of an apple by estimating its diameter and then applying the formula for the volume of a sphere. This should be commented, if only because that particular topic is taught in mathematics only at the end of the eighth grade.

- The apple is approximately spherical in shape, and therefore we can calculate its volume using the formula $V = \frac{4}{3} r^3 \pi$. Since the radius of the apple is equal to 3 cm, its volume is 354.9 cm³.

Density of an apple and its floating

Once they have determined the average mass and volume of an apple, students went on to calculate its density. Those that have concluded that the relation between the densities of apple and water is the root cause of apple's behavior when immersed in water, held that fact up as the conclusion of their research. For example:

“Apple will float on water, because its density (0.75 g/cm³) is less than the density of water (1 g/cm³).”

Some of the students were more explicit:

“Whether an object will float or sink depends on the density of that object, and the liquid it is placed in. If the density of the object is less than the density of the liquid, the object will float, like an apple does when placed in water. I found that the density of an apple is 0.96 g/cm³, and it is well known that the density of water is 1g/cm³”.

Students' opinions on the homework activity

Students were asked to evaluate the homework activity at the end of their reports. Most of the students liked the change and the freedom to find their own solutions to the problem:

“I like this kind of homework, because I found out something new, but not from a book, but by experimenting. I could make my own conclusions.”

“It is different and more interesting than all the previous homework assignments.”

“This homework is motivational because it demands creativity and problem-solving ability and it is a clear example of the things we have been taught in physics class.”

“I like it because it could be done in many different ways and because one had to use household items for measurements.”

Some of the students had a more “gastronomical” approach:

“I preferred experimenting to solving a bunch of numerical problems. Also, I could eat the apples from the experiment.”

The task was a bit overwhelming for one student:

“I didn’t like it very much because it took such a long time to complete. However, I’m sure I will now remember how to calculate density, and why some things float and some sink.”

Some possible benefits for teachers

Teacher should analyze the results of homework assignment and obtain valuable information for further work in the classroom. Some of the more important points would be:

- How does the student determine mass and volume of an average apple? What are his general ideas? How many of those ideas are based on the previous experiences and physics knowledge? Can the student perform a proper measurement, i.e., does she or he zero the scale, submerge an entire apple, make repeat measurements, etc? Does the student use proper units? Can he or she convert units, like milliliters and liters to cubic centimeters and meters?
- Is the student familiar with, and can apply, the formula for calculating density?
- Does the student understand that is it relation between densities that determines whether an object will sink or float? Can he or she notice the contradiction between the calculated density of an apple (in cases when it is greater than 1g/cm^3) and the fact that apples float on water?

Other than finding out skills and abilities each student has, with regards to experimentation, generalization, systematization of results, and the ability to make relevant conclusion based on measurement results, this kind of homework assignment is an excellent way to reinforce and test students’ knowledge on the topic of floating and sinking. Students’ answers provide us with an opportunity to see what alternative conceptions they have, and how far have we progressed in replacing them. For example, a student wrote:

“This research made me realize that apples will float on water, regardless of their size. Both light and heavy apples float. Also, they float in small and large pots.”

This particular student clearly had held alternative conceptions, like the one that it is the size of an object and an amount of water which would affect the outcome of this experiment, but classroom activities and individual assignment had helped him overcome them. On the other hand, some answers will point out the need for further effort in replacing deeply-rooted alternative conceptions.

With classroom time always being in short supply when it comes to teaching science, we should also note the potential for making better use of it, inherent in this teaching method. Students, motivated by

the novel approach offered to them, will readily present their ideas and conceptions while performing investigative experiments at home (Galus, 2003; Vincent et al., 2008). Any classroom time saved by this activity can then be put to good use by revisiting some of the more problematic points.

Students were offered a wide variety of ways to submit their reports, which also helps with gauging the level of their digital literacy.

Analysis of the homework quality in relation to previous knowledge and terms of assignment

To examine the influence of previous knowledge and terms of assignment, we selected two groups of students with equal achievements at the end of fall semester of academic year 2011/2012. These two groups, which we will call A and B, have been given the assignment under different terms:

Group A – The homework was assigned as mandatory: failing to deliver the homework in given time would negatively affect the student’s grade.

Group B – The homework was assigned as voluntary: students were not required to submit finished homework, unless they wanted to. If the student was to deliver a carefully completed assignment, it would have a positive effect on his or her grade.

Each group was split into three subgroups, based on students’ previous grades:

- First – “low performing” students with grades 1 or 2 (out of 5); students that show minimal progress in dealing with the subject matter and reaching requirements from the basic achievement level, or those that fail to do so even with the help of the teacher; usually not taking part in classroom activities.
- Second – “medium performing” students with grades 3 or 4; students making progress and reaching goals set by basic and average achievement levels; students with the grade 4 are also meeting some of the goals from the advanced achievement level; usually moderately involved in classroom activities.
- Third – “high performing” students with the grade 5; students making significant progress and meeting requirements of basic, average and most of the advanced achievement levels with very high degree or classroom activity.

Group A, given the mandatory homework, was comprised of 23 students (7 “low performing”, 8 “medium performing” and 8 “high performing”). The assignment was submitted by 20 students.

Group B, which received the voluntary homework, also had 23 students (8 “low performing”, 7 “medium performing” and 8 “high performing”). 17 students turned in the homework.

We will describe the steps taken to solve this investigative homework by each of the subgroups of the group A (with the mandatory homework), and then we will point out the differences in the quality of solutions when compared to those proposed by the group B (with the voluntary homework).

Group A – mandatory homework

Group A has 8 students from the “high performing” category. All of them have submitted their assignments. Most (7 students) have delivered the homework at school, handwritten on a simple piece of paper torn out from their notebooks. The homework structure was followed correctly, but the assignments didn’t include any drawings or photographs. Of those 7 students, 5 have completed the assignment successfully; one submission was rather superficial, making no connection between the

apple's density and behavior of apple in water; another failed to properly determine the density of an apple. We will describe these assignments in more details.

Four students have selected a single apple that looked about average to them, and then proceeded to measure it using a kitchen scale. These students have properly noticed that an apple will float in water because its density is lower than the density of water, and have found a way to measure apple's volume by submerging it completely, using a thin stick, a knife-tip or a finger. We can conclude that these students have understood that an apple should be forcefully submerged using an object of small volume so that the measurement of volume would yield proper result, although they have failed to clearly state that. The students have calculated volume of an apple by subtracting the volume of water from the volume of water and submerged apple. They have correctly applied the formula for density, used adequate units, and mentioned that the density of an apple, which is less than 1 g/cm^3 , is determining its behavior in water. This property of an apple was observed by the students while measuring the volume, but they have emphasized it again when describing the way an apple acts when placed in water.

One of the students has applied a different method to determine the mass of an average apple. He measured five apples using a kitchen scale, and then divided the mass by the number of apples measured. He then determined the volume of an apple by submerging it into a vessel filled to the top with water, but he didn't say what he used to keep the apple submerged. He measured the volume of the water that spilled over from the vessel and was caught in another container, correctly concluding that the volume of displaced water is equal to the volume of the apple. He then properly applied the formula for calculating density using appropriate units and connected the obtained value with the behavior of apples in water, emphasizing this as the conclusion of his investigation.

These students have given positive evaluations of this kind of homework, noticing that they prefer learning through practical activities to learning using textbooks or solving algebraic problems, and they welcomed an opportunity to test their knowledge in an interesting way.

Two of the students from the "high performing" group have submitted poor assignments. One of them listed only the basic results of measurements of apple's mass and volume, then applied the proper formula and calculated the density of an apple. He noted that an apple will float in water, but offered no explanation, which leads to the conclusion that he failed to connect the obtained density with the fact that apples float in water. His paper doesn't even contain the evaluation of the assignment, demonstrating that even those students that have high grades occasionally approach mandatory homework grudgingly. The other student briefly noted the results of his investigation, mentioning that he determined the volume by spilling water from one vessel into another. However, since he failed to submerge the whole apple, he obtained the smaller value for volume, leading to calculated density of 1.06 g/cm^3 . The student didn't notice that this value doesn't match the observed behavior of apples in water, offering only the comment: "I didn't like the assignment very much, but what can one do."

Only one of the "high performing" students has submitted his homework in an electronic form, on a CD, as a PowerPoint presentation. The assignment contained clear photographs showing the key points of investigation. The presentation was visually appealing. The student measured three apples on a kitchen scale, and divided the result by three, thus obtaining the average mass of an apple. He then picked one of them, without explaining his choice, and determined its volume using a kitchen measuring pot, half-filled with water. Photographs show that a knife-tip was used to keep the apple submerged, but there was no explicit explanation of this action. He applied the proper formula for density and used appropriate units, and noted the connection between the value of density and apples floating in water. His impression of the assignment was: "The homework is interesting because it is unusual and shows practical application of physics."

There are 8 “medium-performing” students, with grades 3 and 4, in group A, 7 of which have turned in their assignments.

Three students have submitted identical solutions, pointing out the well-known problem with homework – copying. The assignment was done poorly, with just a few sentences scribbled down to satisfy the norm. There are no photographs, drawings or comments regarding the assignments. Conclusions of the investigation weren’t pointed out, and no connections were made between density and behavior of apples in water. Looking at their assignments leaves open the possibility that none of those students have actually conducted the investigation. They have stated that they measured the mass of an apple using kitchen scale (220 g) and that the volume was obtained using measuring pot (“the amount of water displaced, that is the volume”). This is followed by the formula for density, leading to the value of 1 g/cm^3 , and the final comment that the apple was floating in the measuring pot. One of the students didn’t even write down the units for mass, volume and density.

In addition to these three copied works, this category saw another example of poorly done assignment, lacking connection between its elements, and without conclusions or comments. It contains of several sentences which can’t even lead us to conclude if the student has even attempted the investigation. She made a statement that the average mass of an apple is 200 g, followed by a vague mentioning that the volume of an apple “can be calculated using measuring pot” and a drawing of apple submerged in water with calculation “ $800 - 650 = 150$ ”. There are no units of measurement, not even in the formula for density, producing the result 1.3.

These four superficially done assignments aside, this group produced three interesting solutions:

One of the students respected the suggested structure, describing each stage of his research and using proper density formula with appropriate units. He used the formula for the volume of a sphere in order to calculate the volume of an apple. However, he probably underestimated the diameter of an apple, leading him to conclude that the density is too high, which he then failed to notice is in disagreement with the way he saw apple behave in water. It is interesting to notice that the student has concluded that apples will float in water, regardless of their mass. Looking at this, we can in turn conclude that even though he had failed to notice the relationship between the fact that apple floats on water and relative density of apple compared to the one of water, he did make some progress towards that conclusion by directly facing and then rejecting the alternative conception that floating and sinking depends on mass alone.

Another student’s homework didn’t reach the proper conclusion, but was done with significant attention and interest. It clearly showed the presence of an alternative conception that “air-filled object will float”. She turned it neatly formatted assignment with three photographs showing the process of measurement of apple’s mass and volume, and the way it floats in water. The students used a kitchen scale to measure the mass and then made an attempt to determine the volume, making an error of not keeping the whole apple submerged during the measurement. The final photograph came with a comment: “As the pictures show, apples float on water... That happens because they have air inside.”

Only one of the students from this group submitted an electronic version of his work, and he is also the only one that used e-mail service to do so. Homework was turned in as a PowerPoint presentation, which was likable, clear and easy to follow. The structure of the assignment was followed, the procedure for measurement of mass and volume was conducted properly, with special note that the apple is to be completely submerged when measuring volume, for which purpose a toothpick was used. The calculated density was properly connected to the fact that apple floated in water. This was one of the best assignments, but was, sadly, lacking any additional comments.

One of the students from this group didn’t submit his homework at all.

The weakest group had seven students, five of which have turned in their assignments. Only one of them had proper structure, but even that one lacked details. Mass and volume were properly determined, and the value of density calculated and connected to the behavior of apple in water with the comment that the assignment was hard, but helped with learning about density, floating and sinking. One of the assignments has solution identical to the three, previously mentioned copied works. The three remaining papers were only formally submitted, since they contained but a few scribbled sentences, lacking almost any meaning, and showing that the students haven't even made an attempt at completing the assignment.

We can conclude that the A group, comprised of 23 students, in which the homework was mandatory, has produced a total of 20 submitted assignments: 4 of those were identical, superficial, poorly done and classifiable as copying; 3 assignments with just a few meaningless sentences, and another 3, done superficially, and with results not in correlation with the way apples behave in water. This data shows that half of the papers were handed in just to satisfy the form, and reflect poor motivation of students. On the other hand, this group has 10 quality assignments, done carefully, 6 of those from the "high-performing", 3 from the "medium-performing" and 1 from the "low-performing" category. Out of these 10, 8 papers are completely correct. The remaining two works show that the students were interested and that a significant effort was put in towards solving the task, but that they haven't succeeded completely.

Only two students of the A group have turned in their work in an electronic form, showing that this mode of assignment doesn't contribute to increase in digital literacy. Most of the students have had positive comments with regards to the assignment, although their comments are short and superficial when coming with the similarly written assignments, and far more detailed when the homework was done with care and interest.

Group B – what can be achieved when students are given voluntary homework

Group B, in which homework was optional, was comprised of 23 students. Assignments were submitted by 17 students: all 8 of the "high-performing" sub-group, and all 7 of the "medium-performing", as well as 2 of the "low-performing" students. Each of the papers was done carefully, with attention and lots of details. 12 out of 17 assignments were turned in electronically: 10 by e-mail and 2 on a CD, in the form of Word (9 students) or PowerPoint (3 students) files. As for the remaining 5 students, two have printed their work out and three have turned in manuscripts.

Completely correct solutions were submitted by all 8 of the "high-performing" students, two of the "medium-performing" and even one of the "low-performing" students. One of the students from the "medium-performing" category has failed to calculate the volume of an apple using formula for volume of sphere, for which she lacked sufficient mathematical knowledge. Remaining 4 of the "medium-performing", and one of the "low-performing" students have made an error by not submerging the whole apple while measuring its volume.

By comparing these results with group A, we can notice that the number of correctly finished assignments is somewhat higher in group B – 11 as opposed to 8 in group A. Out of 11 completely correct assignments, 2 came from the "medium-performing" and 1 from the "low-performing" sub-groups, with the remainder submitted by the "high-performing" students.

On the other hand, while we have only two more papers in group A which demonstrate interest and effort put in by the students, albeit with the wrong final conclusions, there are more of these kind of assignments in group B – a total of six. Like the completely correct ones, these assignments have plenty of details, are obviously done with interest, and the most frequent error is incorrect determination of the volume of an apple.

It is important to note that only 3 of 8 “medium-performing” students from group A have actually made serious attempt at completing the task, instead of simply fulfilling the mandatory form; at the same time, each of the 7 “medium-performing” students from group B has submitted a carefully executed assignment. In addition, after the analysis of the homework and pointing out of the errors, students from the B group have been far more successful in application of what they have learned about apples and their density. They have been more motivated to carefully follow the analysis and have, therefore, held a more open mind towards criticism. They didn’t study only while trying to complete their assignments, but have also collected “the missing pieces” during the analysis, which enabled them to be more successful in later application of knowledge.

The methods of determining mass and volume of an apple used by the students from both groups are mostly similar, but the difference lies in emphasis to detail of research, attempts to achieve more accurate measurement, use of photographs and video-recordings, all much more pronounced in the B group, which had the voluntary assignment.

We will illustrate this with several examples:

“To determine the average mass of an apple, I went to the store and bought a kilogram of apples. They were measured using a digital scale. One kilogram had 5 of them. I numbered them, and used a small kitchen scale (previously zeroed) to measure one at the time. I got the following values: apple no. 1: 180 g; apple no. 2: 195 g; apple no. 3: 200 g; apple no. 4: 225 g; apple no. 5: 200 g. It is clear they all have different masses. I calculated an average mass of an apple by adding them all together and dividing by 5. So, an average mass of an apple is 200 g.”

The student has printed out his work together with photographs of measurement process, starting with one picture showing all 5 apples, numbered using waterproof pen, followed by several images of measurements being made for individual apples, with “close-ups of measurement scale, so that the values can be clearly seen”.

Volume measurements have also included more details. One student has written:

“I have determined the volume of an apple like this. I poured 500 ml of water in a kitchen measuring cup, and then I placed an apple into the cup, and used a thin needle to completely submerge it. I waited for the water level to settle, and read the water level in the cup again. Then I have used the difference of volumes to calculate the volume of the apple. I have repeated the measurement 3 times. The results are shown in the table.”

Table 1. Example table from a student’s report

Number	Volume of water (ml)	Volume of water and apple (ml)	Volume of apple (ml)	Volume of apple (average value) (ml)
1	500	790	290	290
2	500	785	285	290
3	500	795	295	290

Another student’s assignment contains detailed description of volume measurement:

“Since I didn’t have any lab equipment, I used the following ‘trick’: I took an empty tray and placed inside it a bowl, capable of holding all five apples making 1 kg. I carefully topped-up the bowl with water, and then, slowly, added apples, one by one. I have immediately noticed that apples float in water. Water started spilling over from bowl and into the tray. However,

since apples float in water, I asked for members of my household for help with proper determination of their volume: all five apples were simultaneously held submerged by toothpicks. I then removed the bowl with apples in it, and decanted all of the water from the tray into a plastic measurement cup, graded up to 1 liter; I dyed the water using one droplet of ink to get a clearer reading. The measured volume is the volume of all five apples. To get the volume of an average apple, I divided this by five“.

After determining mass and volume of an average apple, students calculated the density. All of the students have used the proper formula and measurement units, with most of the students correctly connecting the calculated density with the way apples behave in water. It is interesting to notice that even some of the students that have made mistakes while determining volume noted that apples float because their density is less than that of water. The value of density, which they've calculated themselves, and which turned out to be greater than the density of water, was dismissed as “wrong, because there must have been some error with conversions between the units – ml to m³ or cm³“.

Students from the B group have, compared to those from the A group, pointed out the important elements of their research more often and with more details. For example:

“During the investigation, I have first assembled required materials and tools: an apple, kitchen scale, measuring pot, water, toothpick, paper and pen and a cell phone with camera to record everything. To determine the mass of the apple I needed to place it on the kitchen scale and measure it. Then I had an idea on how to determine the volume. I poured water into the measuring pot and submerged the whole apple, without it touching sides of the pot, by using a wooden barbecue stick. The water level has increased. The difference between the new and the old level shows the volume of the apple. Once I had both the volume and the mass of the apple, I have calculated the density by dividing mass by volume. I have noted that on paper, and I used the cell phone to make a few photographs during the investigation.”

The B group students have paid more attention to the part of the assignment asking them to note the conclusions of their research. Most of the students have emphasized the results of mass and volume measurements, calculated density of an average apple, and the conclusion that apples float in water because their average density is lower than the density of water.

All of the students from this group have expressed a positive attitude towards this kind of homework assignments.

Conclusions

Investigative homework assignment on apples was developed as a part of a teaching strategy aiming to help students reach proper understanding of density and the way sinking and floating phenomena are affected by the relation between the densities of liquids and objects placed in them. This kind of individual homework is an opportunity for the students to actively do and learn science while saving the classroom time for different activities.

Analysis of quality of investigative homework as a function of student's previous knowledge and mode of assignment has shown that the possibility of choosing whether to work on the task or not has a positive effect on results, regardless of the previous knowledge level. Every assignment done voluntarily shows a certain quality. It is obvious that leaving the assignment optional enhances student creativity, leads to more detailed papers, contributes to clearer and visually more appealing presentations as well as the use of modern means of communication (E-mail) during the learning process.

The most significant result is that the group which had a voluntary assignment had not only the greater total number of correct solutions, but has also shown far more engagement and effort, than was the case with the group in which the assignment was mandatory. The differences are most visible in the category of “medium performing” students: only 3 out of 7 such students from the mandatory group have submitted a quality assignment, showing effort and a will to learn, with the remaining 4 offering papers which reflect only the need to satisfy the form. In the voluntary group, each of the 7 “medium performing” students has submitted carefully prepared assignment. The overview of completely correct solutions, high-quality and low-quality assignments within each of the categories from the groups A and B is shown below:

Table 2. Overview of group A homework results

Group A Mandatory homework	Students	Assignments submitted	Correct solutions	High-quality assignments	Low-quality assignments
High-performing	8	8	6	6	2
Medium- performing	8	7	1	3	4
Low-performing	7	5	1	1	4
Total	23	20	8	10	10

Table 3. Overview of group B homework results

Group B Voluntary homework	Students	Assignments submitted	Correct solutions	High-quality assignments	Low-quality assignments
High-performing	8	8	8	8	0
Medium- performing	7	7	2	7	0
Low-performing	8	2	1	2	0
Total	23	17	11	17	0

One should note that the students which have chosen to complete the task voluntarily were highly motivated to get involved in the analysis of the homework, and willing to look for mistakes by themselves, showing that this mode of assignment improves the communication between students and the teacher while giving feedback, which is an important element of any homework. This has, in addition to the problem-solving process itself, contributed the most to the establishment of applicable knowledge in the B group students, which was shown in later stages of the research.

In the A group, with the mandatory homework, quality assignments were handed in primarily by the “high-performing” students, but even in that category we can see some assignments which are low on content, this also being the main property of most of the “low-performing” and “medium-performing” students’ assignments. The need to simply fulfill the form of the homework, cheating and copying are the negative aspects noticed in this group.

As far as the students’ opinions go on this kind of assignment, it is clear that the students give a big advantage to investigative homework assignments over routine questions and mathematical problems, which are usually assigned for homework.

Our research confirms the opening assumption that homework can significantly contribute to gaining of quality knowledge, but the actual rate of success depends on the kind and mode of assignment. As we have seen, voluntary investigative homework can have a significant impact when it comes to

teaching buoyancy and related concepts. Of course, continued efforts on designing teaching strategies based on active learning with the optimal amount of homework are still needed. We have also shown that more attention should be placed on encouraging “low performing” students to engage in the learning process through the work on investigative homework assignments.

At the end, we want to note that this kind of homework is interesting to grade and analyze, due to large amount of details, ingenuity and effort put in by the students. This can be a nice surprise and motivation for teachers, which is one of the reasons why we recommend this homework exercise.

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