IT SEEMS EASY TO FLOAT, BUT IS IT REALLY?A TEACHING UNIT FOR BUOYANCY

Katarina Susman, Jerneja Pavlin and Mojca Čepič

ABSTRACT
The teachers' prior practice indicates that the conceptual understanding of buoyancy among lower secondary school students is often deficient. Therefore we introduced a new teaching sequence in which students are actively involved and they experience a cognitive conflict. Pre-test analysis shows that students are acquainted with the definition of buoyancy, but their understanding of the phenomenon is rather weak. To expand their conceptual understanding, we designed the activities in such way that students experience buoyancy as a relevant concept for daily life. The proposed student activities are based on team work, hands-on experiments and discussions. The aim of the new approach is to gradually expand students' understanding of buoyancy based on their intuitive notions and pre-knowledge. This context-based approach aims to bring the students' learning closer to their own experiences and share characteristics that make the learning of physics more meaningful. The results of the new approach are evaluated by semi-structured interview.

KEYWORDS
Buoyancy, conceptual understanding, cognitive conflict, school activities

INTRODUCTION

The students' interest in science studies is decreasing in Slovenia as well as in the rest of Europe. One of the goals of teaching natural sciences is to motivate and encourage students for further study in this field. A teacher might achieve this by teaching units that are adequately prepared.

The concepts of density and buoyancy are highly connected to each other and they are both basic concepts important for further study in science. The curriculum for physics in Slovenia places the concept of buoyancy in the lower secondary school for 13 year old students. The classroom activities reported in this contribution and discussion about buoyancy are written to be taught in approximately 3 to 4 school periods of 45 minutes each.

Since the topic of buoyancy and the concept itself demands higher cognitive level, the classes have to be well organized and prepared to achieve sufficient understanding of this concept in such a limited time. We have developed a teaching unit where we have tried to include the students' pre-knowledge with their daily experience. This teaching unit with instructions for teachers is precisely described below. It was constructed with an ambition to help teachers leading students through teaching of difficult physical concepts such as buoyancy.

The teaching unit was performed in two classes of lower secondary school. With ambition to answer the research question, "How, and to what extent, do students develop the concept "buoyancy" by means of the designed unit?" we made a questionnaire and semi-structured interview. At the end of the lessons, the students' knowledge was tested with a questionnaire (29 students). Three months after the lessons we have done the qualitative investigation through semi-structured interview about the classes and students' knowledge about buoyancy. The time period of three months was chosen because we wanted to know what stayed in students' long-term memory.

TEACHING UNIT

The teaching unit about buoyancy is based on the constructivist approach. The discussion and the students' activities arise from their daily life and specific common problems. All these activities should stimulate students for active reasoning and finally lead them to understand the concept of buoyancy.

The presented teaching unit is divided into four sub units. Each subunit takes one physics lesson and has the title that is not usual for traditional classes. The title also serves as a starting motivation.

I float, you float, she/he/it floats…

The first subunit serves as a motivation for the whole topic of buoyancy. The aim of this lesson is to define the criteria for floating and sinking of a specific object and to discuss which parameters influence the floating. The active thinking during the practical work and the discussion lead students to achieve this goal.

A good introduction about sinking and floating should be made at the beginning of the lesson. Students experience floating, swimming, sinking, and they have their intuitive preconceptions about it. The teacher should find out the actual knowledge of the students and the main misconceptions. It is important to discuss the terms "floating" and "sinking" and the factors that influence it. All factors proposed by students should be written on the blackboard and discussed during the lesson. On the question, "Which objects sink and which float?", students often answer that the objects with low weight float and those with high weight sink.

Experimental activities include low cost and widely available material. All one needs for this practical work are straws, paper clips, scissors and water tank filled with water. Out of this material, students make different floating and sinking objects, called "divers" (Čepič, 2006; Planinšič et al. 2004). They cut an undefined length of a straw and fold it as shown on the Figure 1a. Two ends of the bent straw are bound together with a paper clip (Figure 1b). To change the mass of the diver some more paper clips can be fixed on the clip that binds the straw ends (Figure1c, 1d).

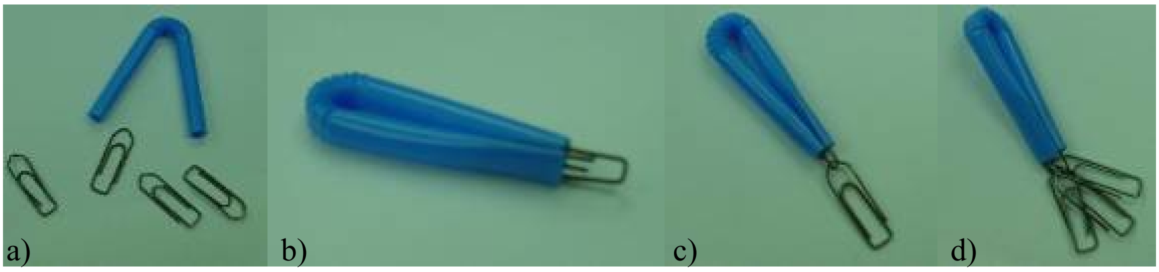


Figure 1. A construction of "a diver": (a) A straw and paperclips; (b) a straw bound with a paper clip; (c), (d) affixing the additional paper clips.

Students make their own divers and let them float or sink in the water. The class defines the criteria to ascertain which diver floats better. The discussion leads many students to face cognitive conflict, since they are convinced, that objects with lower weight float better. The diver that floats better even if it has higher weight than another can be easily made. For example, two divers have different number of paper clips (different masses) and different lengths of the straws. The diver with higher weight floats better if the straw is long enough.

From this point, the teacher leads students to think about experiments showing the interdependence of weight and floating. Students must adopt the relation between weight of the diver and its volume. If the weight is to be changed, the volume must remain constant. In practice it means that the divers have different numbers of paper clips and the same straw lengths (approximately the same volume) (Figure 2).

The first part of the puzzle is put in the right place when students compose a statement like: The lower the weight of the diver, the better it floats, if the volume remains constant.

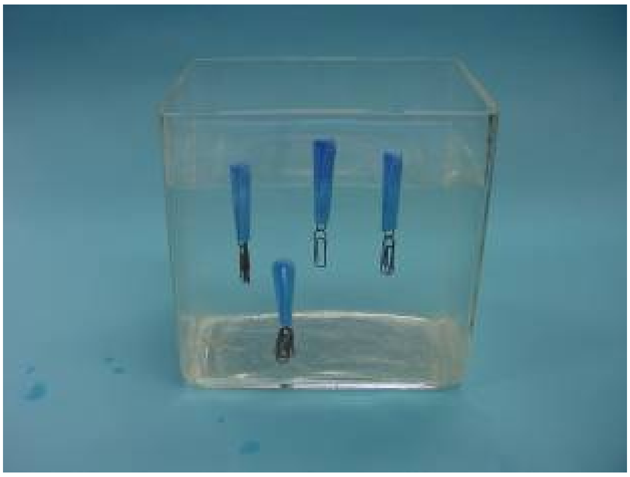


Figure 2. How weights of the diver influence floating if the volume is approximately constant.

The second part of the puzzle must reveal how volume influences floating. Through experiments and discussion students should realize the necessity of changing the length (volume) of straws and not changing the number of paper clips. The divers have different straw lengths and the same number of paper clips (approximately the same mass) (Figure 3). The final statement of this part would be: The greater the volume of the diver, the better it floats if the weight remains constant.

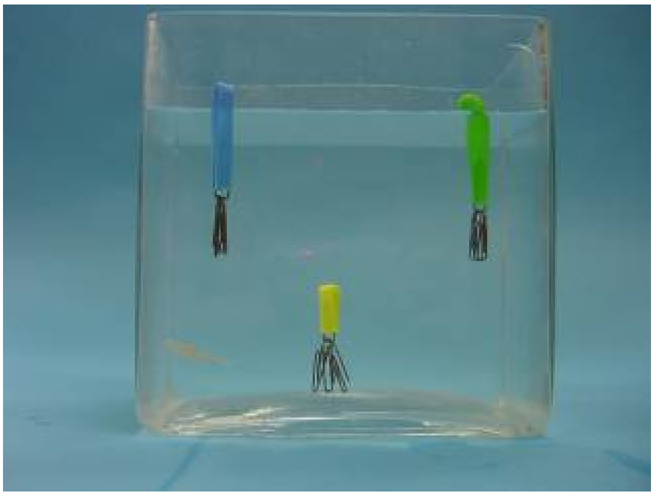


Figure 3. How volume influences the floating if the mass does not change significantly.

The teacher's role is very important in this part of the session. Teacher leads the discussion as to why the approximation is made to determine the mass and the volume in the previous tasks as constants. In the first task the volume change due to different number of paper clips is ignored and in the second case the mass change due to different length of straws is ignored.

Students realize that the volume and mass influence the buoyancy. Is there any other concept that includes both the mass and the volume? The final discussion leads students to connect all previous ascertainments with the concept of density. The term of average density leads toward the answers on the question of why the amount of air in the straw influences floating.

At the end of the first session students understand the concept of density and are able to connect it with floating. Through the discussion students should overcome the cognitive conflict and complete the puzzle about floating.

Eureka!

The title of the second subunit opens the discussion about Archimedes and can be used as an interdisciplinary connection to history and chemistry. The main goal is to find out what buoyancy is and how one can "feel" it. The discussion plays the major role in this lesson. The discussion is followed by an experiment that enables every student to experience the effect of buoyancy.

One needs a huge rock, a rope and a container with water. The rock is tied with the rope and a handle is made out of the rope. Each student lifts the rock using a handle and repeats this in the water. They feel that the "weight" of the rock in the water is less than the weight out of the water. Usually students are very enthusiastic about this experiment and they are often very surprised. Some of them admitted that they had not expected such a difference in the "weight".

This observation raises further questions: What is the nature of the change in "weight". Does the "weight" of a rock change when it is placed in the water? Is it really the "true weight" that changes, or something else that influences the rock? All these questions should be answered through conversation and two new terms of "apparent weight" and "buoyancy" should be introduced. The "apparent weight" is a weight of an object submerged in the liquid reduced for buoyant force. At this point students should recognize the buoyancy as the influence of water on submerged objects. The final statement should be similar to this: The buoyancy is the force that opposes the weight (has the opposite direction) and consequently causes the apparent weight to be less than the weight.

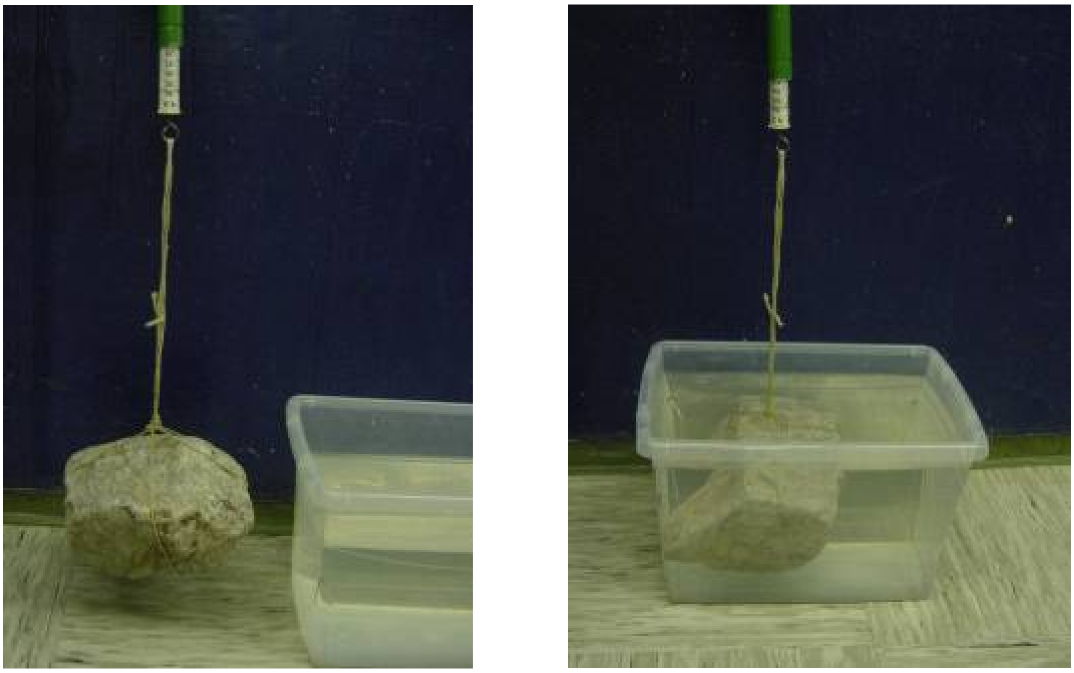


Figure 4. Measuring the weight (left) and apparent weight (right) of the rock.

The next step is the quantitative determination of the apparent weight, the true weight and the difference between them. This can be done by using a dynamometer (Figure 4) and the results should be written on the blackboard to be discussed later.

When the stone is submerged in the water students also notice that the level of the water rises. The stone displaces some amount of water, but how much? They mark the maximum level of the water, and after that they take the stone out of the water. Students think about the amount of water that needs to be added to reach the previous water level and the amount of water displaced by the stone. They make a link to the volume of the stone and to the measurements. The same water level is reached whether the water is added or when the stone is submerged in the water (Figure 5). This measurement reveals that the amount of added water (water displaced by the stone) has the same weight as the difference between the real and apparent weight. It looks like coincidence, so the measurements should be performed using some other object or another stone. Students realize that the weight of added or displaced water is the same as the difference between apparent and true weights. At this moment the teacher leads students to cognize the buoyancy as the difference between true and apparent weight that is quantitatively equal to the weight of displaced water.

Figure 5. When the rock is submerged the water level rises and the level of the water is marked on the container. How much water should be added to reach the marked level?

Can we write the equation for buoyancy?
Since the buoyancy has been discussed only qualitatively, the following lesson is formed to expand the theme. After the revision of the knowledge from previous hours, a new research question is formulated. How can we write an equation using the facts that we already know? What factors influence buoyancy? Students list their propositions and the teacher writes them on the blackboard. After that, the teacher gives students a box of different blocks, objects and liquids that should be used in the experimental part of the lesson. Students consider different experiments to determine the influence of the proposed factors on buoyancy.

The main factors that are usually proposed by students include: the mass of the body, the volume of the body, the density of the body and the density of the liquid.

The proposed experiments and conclusions are:
- Density of the object
One needs two metal blocks with different densities and constant volume. The blocks are submerged in the water and the buoyant force is indirectly measured with a dynamometer. The buoyant force is the same in both cases therefore the density of the objects does not influence the buoyancy. Many students face a cognitive conflict at this point since it is difficult to accept that the density of the object does not influence buoyancy

- Density of the liquid
One needs at least two liquids with different densities and one object, which sinks in both of them. First the object is submerged in one liquid and the buoyancy is measured as in the previous experiment. The procedure is repeated with the second liquid. Since the buoyancies are different, the density of the liquid influences the buoyancy.

The fact that liquid density influences the buoyancy can also be observed without measuring. The teacher could show the experiment with an egg in plain water and in salty water. The same egg sinks in plain water and floats in salty water. The buoyant force on the egg that sinks in water is smaller than the buoyant force on the same egg that floats in the salty water. However one has to bear in mind that the buoyant force is equal to the weight of the floating object (Figure 6).

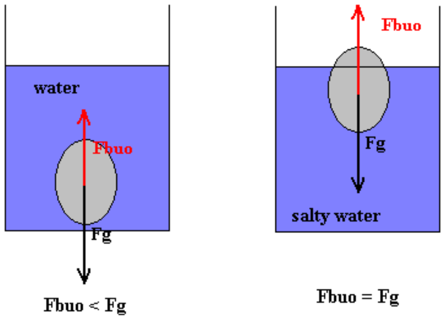


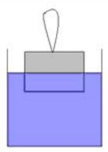
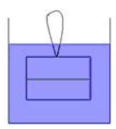
Figure 6. An egg in the water and in the salty water

- Mass of the object and volume of the object

The mass and the volume of an object are connected to each other through the concept of density therefore it is not possible to perform the experiment, where only mass (volume) would change. If one changes the mass (volume) of an object, but the volume (mass) remains constant the change in material is unavoidable. The following set up is proposed to detect the change of volume and the change of mass in the same experiment.

One takes two blocks with different masses that have the same shape and volume. Each should be gradually submerged and the buoyancy should be measured with a dynamometer. The results should be written in a table (Figure 7).

Figure 7. A table of mass and volume dependencies on buoyancy with sample results and comments.

Submerged volume	First block with mass m_1			Second block with mass m_2		
	Weight $F_{g,1}$	Apparent weight $F_{g,app,1}$	Buoyancy $F_{buo,1}$	Weight $F_{g,2}$	Apparent weight $F_{g,app,2}$	Buoyancy $F_{buo,2}$
	1,75 N	1,5 N	0,25 N	4,75 N	4,5 N	0,25 N
	1,75 N	1,25 N	**0,5 N**	4,75 N	4,25 N	**0,5 N**

The volume of the submerged part of the block influences buoyancy.

The buoyancy does depend on the mass of the object.

The following conclusions of this experimental work present the basis for developing the formula for buoyancy.

The density of the submerged part does not influence the buoyancy.
The density of the liquid influences the buoyancy.
The mass of the submerged body has no influence on the buoyancy.
The volume of displaced liquid (volume of submerged part of the body) influences the buoyancy.

The equation could be written step by step including the knowledge from previous lessons and these conclusions.

The buoyancy is equal to the weight of displaced liquid:

$$F_{buo} = F_{g\,displ.liquid} \qquad (1)$$

$$F_{buo} = m_{displ.liquid}\,g \qquad (2)$$

From the equation of density the mass of displaced liquid is derived and replaced

$$F_{buo} = \rho_{displ.liquid} V_{displ.liquid}\,g \qquad (3)$$

The equation evidently shows that buoyancy depends on density of a displaced liquid, on volume of displaced liquid and on gravitational acceleration (i.e. the weight of displaced liquid). The lesson ends with the discussion about buoyancy in different liquids including air and explanation of gravitational dependence.

Buoyancy and the daily life

The last lesson checks and improves the knowledge about buoyancy. Furthermore, it motivates students to confront daily problems from a scientific point of view. The concept of buoyancy has to be properly connected with the first lesson about floating and sinking. Qualitative comparison of buoyancy and weight in the case of floating and in the case of sinking objects should be exposed in the conclusions.

A few typical exercises from school textbooks that strengthen students' skills in calculation and equation manipulation should be done. The most important part is to check their conceptual knowledge and its transfer to the daily problems. To achieve these goals some of the problems are presented below. Each student has to write his/her own explanation in the notebook and afterwards the debate should start.

1. Why does the steel ship float, but the block of the same mass of steel sinks?
2. What happens to the ship, when it sails from a river into the sea?
3. How could you explain the experiment where the same egg floats in one liquid and sinks in another? Arrange the densities of the liquids and the egg.
4. Explain why CocaCola light floats, and why normal CocaCola sinks (Figure 8), (http://thefoodgeek.com/food/diet-coke-floats)

Figure 8. A Coca Cola problem.

5. Predict what will be the result of the experiment if wooden bowls (figure 9) are placed in the water. Explain the result of this experiment (Razpet, 2006).

Figure 9. Two wooden bowls of the same size and material, one of them with a hole on the bottom, are placed in the water.

QUALITATIVE ANALYSIS OF TEACHING UNIT

Cooperation of the students during the lessons

During the classes students cooperated well. All the activities were finished by the majority of students. Furthermore some of them asked for additional information after the classes. Sometimes an interesting discussion developed on presented details or experiments. In our opinion such discussion leads to deepening of their knowledge and contributes to their individual occupancy with science topics. After the completed classes on buoyancy, a greater level of conceptual knowledge and ability for solving problems from daily life were noticed. The students' answers on the previous questions (1.-5.) are summarized below:

1. Students explained the floating of the ship and sinking of the block by using the term average density and the influence of the air inside the ship on the reduction of the average density.
2. They have connected this problem with the egg in different liquids performed during the third subunit. They realized that the density of the sea water is greater than the density of the river water. From these considerations some (6 out of 29) of the students successfully solved the problem.
3. The majority (25 out of 29) of the students gave the correct answer since the problem was explained in previous lesson. The goal of this task was to check if they assimilated the knowledge in a way to be able to describe it with their own words.
4. Some of the remarks of the Coca Cola problem were:
    a. "There is less liquid in one of the cans."
    b. "There is more air in Coca Cola light."
    c. "They have different densities."
    d. "Are both of the same size?"

    After that the teacher read from the cans the contents of the Coca Cola. Some of the students found out that the amount of the sugar influenced the density of Coca Colas.
5. The majority (26 out of 29) of the students predicted that the wooden bowl with the hole will sink. They were surprised because the experiment did not confirm their predictions. Only few (3 out of 29) of them did not agree and they gave a logical explanation for this problem. Their conclusions were that both of the bowls are wooden, and the wood has a lower density than the water. Consequently the average density of wood and water together will be smaller than the density of the water itself. Therefore both bowls will float.

Questionnaire and semi-structured interview

At the end of the lessons on buoyancy students filled in the questionnaire. The questionnaire was made of a general part and a test of knowledge (14 exercises). The general part gave us data about students' interests. The test with the 14 exercises covered the concepts of density and buoyancy. The difficulty level and the type of the exercises (e.g., open-ended questions and closed question) varied significantly.

With this part we tested students' knowledge and understanding of the concepts of density and buoyancy. Some descriptions of exercises and students' answers are given in Pavlin *et al.* (2008).

The focus of this article is placed on the description of teaching unit and response of students on it. The results of questionnaire do not give us information about impressions of students and understanding of experiments they did. Therefore we decided to use semi-structured interview as an instrument to evaluate the teaching unit.

5 out of 29 students of the class were selected after a period of three months for interviewing. Our objective was to detect the level of their knowledge and to obtain information on the extent to which they could recall the structure of the lessons. The range of details they could remember was surprisingly extensive.

To obtain a clear idea of atmosphere in the classroom during the classes the semi-structured interview was selected. The basis of the interview was the following questions:

- Name five words that you associate with the lessons on buoyancy.
- In which way do you think these classes differ from traditional classes?

Later on the level of knowledge was detected through sub questions, based on previous answers.

The outcomes of each of the interviews are presented below.
First conversation was performed with two students who were highly interested in physics. The students are labeled with numbers.
Student 1 mentioned the following words: Eureka, straws, a rock, wet table, a bowl with a hole in the bottom, density.
Student 2: The stone in the water, wood, buoyancy, apparent weight.

The next questions were about the words they expressed, their meanings, and experiments they remembered. Both of them gave accurate answers and descriptions. Both of them were indicating a great level of knowledge and communication abilities with correct physics terminology. Through the interview they remembered almost all details from the classes. They both noticed a great difference between these classes and traditional classes. *"The classes were interesting, full of conversation and especially full of interesting experiments"* said student 1. Student 2 agreed and added that the activities were following each other in a logical order - step by step - so everyone was able to follow. They said that the classes were great due to individual work and the experiments they were able to carry out by themselves. They both admitted that they had learned more than from traditional classes, where only few demonstrations are usually shown by the teacher. At the same time they exposed the problem of those students, who did not cooperate in active thinking and spend hours just for having fun. Their opinion was that these students probably did not learn as much as they would by traditional classes.

Student 3 with no special interest in physics activities was interviewed next. The words that the student associated with the classes were: divers, CocaCola, buoyancy. This student described the activity with the divers and the Coca Cola problem. The concept of buoyancy was explained correctly. There were no special details described and no special enthusiasm detected through the conversation. On the question about classes and comparison with traditional classes, we were given the answer that it was too much discussion and not enough traditional exercises in the notebooks. The good parts of the classes were experiments, which were interesting and understandable.

At the end an interview was done with two students regarded as average at physics. The words they quoted were practically the same as the first two students. Their knowledge detected through the interviews was very good, including the terminology and explanations of the activities. They both like this kind of class and made a note that one can get a lot from it only through thinking and following the course. They both considered lessons as interesting and fun and they valued their knowledge of buoyancy as very good. Similar to the first two students, they stated that weak students often take the classes just for fun.

CONCLUSIONS

Many surveys confirm that the concept of buoyancy is difficult to understand and deserves a precise explanation and well prepared classes (Loverude et al., 2003; Heron et al., 2003; She, 2005). The pilot study presented above is a starting point for our future research about difficult physical concepts. Based on the findings of this pilot study it can be concluded that the concept development of the phenomenon "buoyancy" can take place by means of the proposed unit. The students develop the meaning of the concept using their intuitive notions and by discussion from which a more scientific meaning can be developed.

The number of interviewed students was low, so that limits the conclusions. However, there are reasons to believe that the learning by the proposed unit is a promising strategy for teaching buoyancy. Students easily followed the course and it is worthwhile to follow up this pilot study with larger groups of students and different teachers.

"You made physics classes interesting, I would be happy if all classes were like these." This sentence expressed by one of the students motivates us to improve these lessons and spread the idea and the concept of this unit to other teachers.

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Katarina Susman
Faculty of Education
University of Ljubljana
Kardeljeva ploščad 16
1000 Ljubljana, SI
Email: katarina.susman@guest.arnes.si

Jerneja Pavlin
Faculty of Education
University of Ljubljana
Kardeljeva ploščad 16
1000 Ljubljana, SI
Email: jerneja.pavlin@guest.arnes.si

Mojca Čepič
Faculty of Education
University of Ljubljana
Kardeljeva ploščad 16
1000 Ljubljana, SI
Email: mojca.cepic@ijs.si