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Let's Repair the Broken Galileo Thermometer

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We have developed and verified laboratory work as guided inquiry for upper secondary level students, focusing on conceptual understanding of the physical principle that forms the basis of temperature measurement, and on improvement of selected skills. Conceptual pre-test questions initiate the students' interest and help identify input misconceptions. Using the method of interactive lecture demonstration, the students are introduced to the measurement principles of the Galileo thermometer. The students are then set the problem of how to repair a broken thermometer when tap water is used instead of ethanol. Since the density of water is greater than that of ethanol, the buoys must be adjusted by the students to achieve correct temperature measurement. The next steps of the activity have a hands-on orientation. The students work in pairs, guided by worksheet instructions. At the end of the activity, they complete self-assessment rubrics focused on skill improvement and final conceptual understanding. The results of the conceptual pretest questions and of the self-assessment rubrics from 461 participants are analysed and recommendations are made for teachers.

Keywords: conceptual understanding, Galileo thermometer, guided inquiry

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Popravimo pokvarjen Galilejev termometer

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Razvili in evalvirali smo laboratorijsko vajo, vključujoč učenje z raziskovanjem, za dijake, osredinjeno na konceptualno razumevanje fizikalnega principa, ki je osnova za merjenje temperature, in na izboljšanje izbranih veščin. Vprašanja na predpreizkusu znanja spodbujajo dijakovo zanimanje in pomagajo identificirati začetne napačne predstave. Z uporabo metode interaktivne demonstracije na predavanju se dijaki seznanijo s principom merjenja z Galilejevim termometrom. Dijaki nato oblikujejo problem, kako popraviti pokvarjen termometer, ko je uporabljena voda iz pipe namesto etanola. Ker je gostota vode večja kot gostota etanola, morajo dijaki prilagoditi plovnost termometra, da dosežejo pravilne meritve temperature. Naslednji koraki aktivnosti vključujejo preproste poskuse. Dijaki delajo v parih, sledijo navodilom za delo z delovnih listov. Na koncu aktivnosti izpolnijo vprašalnik za samooceno s poudarkom na izboljšanju veščin in končnem konceptualnem razumevanju. Rezultati predpreizkusov znanja in vprašalnikov za samooceno 461 udeležencev so analizirani in podana so priporočila za učitelje.

Ključne besede: konceptualno razumevanje, Galilejev termometer, vodeno raziskovanje

Introduction

Contemporary science, engineering and technology bring a vast array of topics, the understanding of which is required in order to motivate and engage students for their sustainable development in the future. In formal education, there is a great deal of inertia and conservatism, which unfortunately results in a failure to address content innovations systematically and dynamically. Our aim is to suggest an approach to processing current topics that follows the school curriculum and opens up new horizons for the students. In order to ensure the development of these topics, we seek to demonstrate their benefits and strengthen the determination of teachers to include them in school education programmes.

Flotation, buoyancy force and the Archimedes' principle are among to the basic topics of physics courses. We can determine the existence of a buoyancy force when we observe diving and flotation, and this topic is reasonably easy to remember for the vast majority of students. In our practice, however, we have encountered mostly just learned facts, without conceptual understanding. In order to solve new situations, only a consistent understanding can ensure success.

Just the key concepts, which require conceptual understanding, are appropriate topics for inquiry educational activities. The interactive nature of the suggested customised activity creates understanding of the topic or concept. The activity is conducted with a worksheet, or with the instructions of the teacher, with partial steps including assessment and discussion. The student first formulates his/her findings using existing knowledge, and his/her results are then corrected in the discussion with the teacher. An important part of the follow-up of the educational activity is formative assessment. Students use self-grading instruments to express the degree of satisfaction with their own level achieved in the area of conceptual understanding, as well as the development of selected skills. We classify this educational approach as "guided inquiry".

Guided inquiry brings a substantial change to the teacher's educational approach, whereby the "new concept" is the result of the student's activity as a learner. As well as obtaining new skills, new findings will be formulated at the end of the activity. Guided inquiry allows for the development of a skill through experimental activity; its key component is a problem, a challenge for any student.

In order to implement guided inquiry in schools, it is necessary to prepare teachers on how to manage the entire educational process.

The complexity of such a process is illustrated by the findings of the IAP report (IAP, 2010), which identified six issues associated with efforts to introduce inquiry activities into secondary schools where traditional teaching methods are used:

- The demands of the curriculum content and lesson schedules.
- The impact of tests and examinations; particularly the use of results for high stakes decisions affecting students and teachers. This creates pressure, which distorts content and teaching methods, deters the use of inquiry and obstructs the formative use of assessment by teachers.
- The relevance of science as perceived by students.
- Teachers' subject knowledge.
- The use of new technologies, which, although it has many benefits, can produce situations where students learn in isolation.
- The balance of continuity/discontinuity at transfer from primary to secondary level. An abrupt change in school culture, organisation of teaching and nature of science teaching at transfer from primary to secondary school can cause a decline in performance and in effective response to science.

From our perspective, it is necessary for the teacher to gain self-confidence and inner conviction about the educational feasibility of the activity. Preservice teachers are significantly more likely to use innovative approaches than older teachers with years of experience.

Teachers may fail to fully understand the concept of inquiry for many reasons. Many teachers have acquired little or no scientific research experience in their own education, which may contribute to their lack of scientific content knowledge (Zion et al., 2007). Furthermore, teachers' lack of knowledge about the nature of science can be a barrier to implementing IBSE-teaching (Roehrig & Luft, 2004). Most teachers have inadequate ideas about science, and there is a complex relationship between teachers' stated beliefs about science and how they actually present science in their classrooms (Abd-El-Khalic & Lederman, 2000). Studies show that many teachers teach scientific content in preference to the nature of science (Sadler, Amirshokoohi, Kazempour, & Allspaw, 2006).

For the student, active learning involves a significant change in communicating skills and the acquisition of new knowledge. In an effort to encourage a change in the approach to active learning, we utilise the informal environment of the centre for the popularisation of science SteelPARK Košice (www.steelpark.sk). The student, as well as the teacher or lecturer, pays more attention to his/her own educational activity, teamwork, results and findings, and to the formulation of conclusions. In conjunction with attractive content and modern methods, the educational activity contributes to more spontaneous student behaviour and greater motivation for work. In addition, our fun science centre exhibition offers visitors active interaction with more than fifty exhibits demonstrating the story of steel, from the field of metallurgy, geology, physics, chemistry, safety, engineering and others. The exhibits are prepared in such a way that it is possible to carry out observations with them repeatedly without the help of an instructor. The visitor usually perceives the activities as a game, the aim of which is to observe a selected phenomenon.

Within the SteelPARK centre, we have organised the Inquiry Science Laboratory, which has been operating successfully for the last three years. So far, we have designed and implemented 16 educational activities at the level of guided inquiry. Groups of students participate in research activities under the supervision of a trained lecturer (a future teacher). The lecturers are students, including PhD students, and future teachers of science subjects. School classes, which are divided into two groups, attend a laboratory where they participate in parallel activities led by trained instructors. The monthly attendance is approximately 400 students, and a total of around 9,000 students from secondary and elementary schools have attended to date. The teacher follows the work of the lecturer, evaluates the progress of the activity, and receives all of the supporting materials for applying guided inquiry in his/her own teaching. Future teachers gain practical experience with innovative approaches to teaching and the associated assessment tools, while students are encouraged to engage in active discovery, bolstering their self-esteem. Verifiable educational activities and a database of research findings are shared with a wide community of teachers in order to encourage the STEM system. One of these activities is: Let's Repair the Broken Galileo Thermometer.

Methods

Action research principles were used to validate the prepared learning activities. The objectives are:

- to structure and develop a conceptual understanding of the key topics in physics education;
- to prepare the activities using the inquiry-based science education (IBSE) approach, in order to improve conceptual understanding and develop research skills;
- to prepare, support and motivate future teachers and practising teachers to teach with the use of IBSE.

The respondents are students of primary (age 12–15 years) and secondary schools (age 15–18 years), future teachers and practising teachers. The instruments for the implementation of the research are: observation of the work of the lecturers and students, evaluation of questionnaires of teachers supervising course activities, interviews with lecturers, analysis of completed worksheets, analysis of students' answers to conceptual questions, and the development of self-assessment sheets. The resulting products are educational activities and recommendations on their implementation.

Research design

The method of design-based research was used for educational materials, development and guided inquiry method proofs. Design-based research can be described as a cycle: analysis of a practical problem, development of solutions, iterative testing of solutions, reflection and implementation (Reeves, 2006).

The central element of inquiry activities is a problem, an educational challenge for a student and his/her enthusiasm and motivation to solve it. One interesting problem with an experimental approach is the issue of the Galileo thermometer (Güémez, 2009).

Problem

Glass-walled buoy-like spheroids containing a coloured liquid are immersed in an enclosed cylinder full of liquid. Attached to each spheroid is a small metal tag indicating a temperature in a range of two degrees Celsius. At a given temperature, some of the spheres rest at the bottom of the cylinder, while others float at the top of the liquid column. In an ideal case, one buoy floats at a particular depth close to the middle of the cylinder. Such a device is called a Galileo thermometer. Galileo thermometers, with a predetermined number of coloured spheres usually floating in a high cylindrical container, are well known and widely used (Ucke, 2017). The Galileo thermometer was not, in fact, invented by Galileo himself, but Galileo did discover the principle that liquids change their density with temperature. The small glass spheres are partly filled with different coloured liquids. The composition of these liquids is not important for the functioning of the thermometer; they merely function as fixed weights and their colours are only for decoration. The liquid in which the bulbs are submerged is not water, but some organic compound (such as ethanol), the density of which varies with temperature more than water does. Temperature changes affect the density of the outer clear liquid, thus causing the bulbs to rise or sink.

P1: How does such a device work?

Each of the floating spheroids displaces a weight of fluid equal to its own weight, while the others either displace too much or too little liquid to float at a specific position within the cylinder. Such a statement derives from Archimedes' principle.

Figure 1. Galileo thermometer.

The column of isothermal liquid has a density ρ that depends on the depth in the fluid given by (Nickas, 1989):

$$\rho = \rho_o \,(1 + \frac{g\rho_o y}{B})$$

Where: B is bulk modulus, ρ_o liquid density at the surface, y depth in the liquid, g gravitational acceleration.
Bulk modulus is defined as:

$$B = \rho_o \frac{dp}{d\rho}$$

Where: $dp = g\rho_o dy$
Once the buoy is floating, we set the density of fluid equal to that of a buoy to produce depth of floating, y:

$$y = \frac{B(\rho_b - \rho_o)}{g\rho_o^2}$$

The change in temperature changes the density of the liquid. The surface density can be written as a function of temperature T as:

$$\rho_o(T) = \rho_o(T_o)(1 - \beta(T - T_o))$$

Where the quantity β is the coefficient of fluid volume expansion, and T_o is the initial temperature.

The change in temperature influences the buoy depth by:

$$\Delta y = \frac{\beta B}{g\rho_o} \Delta T$$

The coefficient of the thermal volume expansion of glass is up to 20 times less than that of liquids at room temperature. The spheroid will respond reasonably negligibly to temperature changes compared to the responding liquid. Only the liquid in the cylinder is considered temperature sensitive for the action. The spheroid rises with a decrease in temperature and sinks with an increase. The correct temperature is indicated by the temperature on the suspended floater. If there is no suspended floater, the temperature is bounded between that of the upper and lower floaters. A change in temperature would require a "new" floating spheroid to replace an "old" one at the same depth.

The sensitivity of such a thermometer would be given as the ratio of change in depth and change in temperature ($\Delta y/\Delta T$). For water at room temperature ($\beta = 2 \,.\, 10^{-4}\ {}^{o}C^{-1}$, $B = 2 \,.\, 10^{-9}$ Pa, $g = 10\ ms^{-2}$, $\rho_o = 10^3\ kgm^{-3}$), it is around 40m/°C. However, for such a sensitive device one would have to construct buoys with differing masses of only ± 0,2mg/cm³ of volume for 1°C temperature change. Galileo thermometers are now built and sold all over the world for decoration purposes.

P2: Our favourite thermometer was broken during cleaning, but the buoys remained. You want to fix the thermometer using a beaker filled with water instead of ethanol. Suggest how you need to modify the buoys in order to make the thermometer work correctly again. Verify your proposal with an experiment.

How is the task solved?

In order to solve the assignment, we will use: two beakers, glass, water, buoys from the original thermometer, metal wire, digital scales with a precision of ±0,01 g, pliers, a ruler and a digital thermometer.

Worksheet instruction for students.

1. Verify how the buoys behave in water.
   - Measure the temperature of the water in the glass and note down the data.
   - Carefully and gradually dip all of the buoys into the beaker with water. Note down how the individual buoys behave. We know that $\rho_{etylalcohol} = 789\ kgm^{-3}$, $\rho_{water} = 1000\ kgm^{-3}$

- Decide whether it is possible to determine the temperature of the water from the layout of the buoy.

Write down your observations.

2. Teach the buoys to measure the temperature even when they are submerged in water.
   - Using a digital thermometer, measure the water temperature in the cylinder and record the data.
   - Select a buoy with a temperature lower than measured, and insert it carefully into the cylinder.
   - The buoy should fall to the bottom. However, water is denser than ethanol, so the buoy remains just below the surface. Select the buoy. Cut a piece of wire, measure its length and weigh it. Write down the measured values. Hang the wire on the label of the buoy and then put it back into the cylinder with water.
   - By gradually shortening the wire, find the appropriate weight at which the buoy sinks very slowly to the bottom. Determine the weight of the wire for each length, and gradually complete a table with the data.

   Work in a group. Write down your findings.

3. Verify that the buoy recognises a different temperature.
   - The buoy calibrated on a lower temperature than the temperature of the water in the cylinder slowly sinks to the bottom.
   - Insert the buoy into water that is colder than the water to which it has been calibrated.
   - Describe its behaviour and decide whether it responds correctly to the water temperature.

   Work in a group. Write down your findings.

4. Suggest a procedure for the “warmer” buoy.
   - Design a procedure for adjusting a buoy to define a temperature greater than the actual temperature of the water in the cylinder.
   - Describe how you would verify its functionality at a different temperature.

   Discuss in the group. Write down your procedure.

5. Formulate the conclusion of today’s measurements.

   Discuss in the group. Write down your results and conclusions.

We propose this educational activity as guided inquiry. The teachers involved in the study were prepared for the implementation of the activity in both aspects: professional and research. For verification, we used the informal environment of the science centre, where we had prepared five workplaces for groups of two or three students. Mapping the level of conceptual understanding, we executed a series of questions in a concept test, which the students completed in the introductory part of the activity. The lecturers only commented briefly and evaluated the answers. The teacher supervised the course of the activity and evaluated the checklist. At the end of the activity, the students completed self-assessment sheets. The data from the worksheets, the concept tests, the self-assessment sheets and the teachers' evaluations were processed during the activity, then summarised for all of the participating groups of students. The result of the research is an educational activity backed by support materials, as well as the formulation of recommendations for its implementation.

Sample

The prepared activity was suggested to schools as part of school excursions to the science centre. After discussing the topic as part of their school study plan, teachers enrolled their school class of lower secondary (12–15 years old) or upper secondary (15–18 years old) students. A total of 461 students from surrounding schools, both rural and urban, participated in the study. The sample can be considered random, as the availability of students from both urban and rural schools was without significant restrictions. The students were in groups of five, three or two, working much as they do during normal school classes. The implementation of the activities took 60 minutes. In each activity, there is basic content and augmented content, so the lecturer can effectively use the time according to the readiness of the students. The science teacher observed the whole process and was able to assist our lecturer in communicating with the students.

Instruments

The input data was collected using a questionnaire consisting of four questions focused on students' preconceptions of floatation, the principle of buoyancy forces, and the topic of temperature measurement.

Q1: List the various types of thermometers.
Briefly write down the principle governing the operation of a thermometer.

Q2: Draw in all of the forces that act on the body submerged in the liquid in the picture. Mark the forces and write down what they are called.

Q3: Three bodies are placed in a container with water. One is on the bottom, another is floating in the middle of the container, and the third is floating on the surface. Compare the density of the bodies with the density of water.

Q4: Objects submerged in liquid are buoyant. How do you explain the fact that liquid (e.g., water) knows that it has to float the submerged body?

The answers to the following questions are written on the student worksheet:

W1: Temperature is usually measured in °C. Describe some temperatures that we can encounter in our everyday life. You may have encountered a temperature measured in K or °F. Explain how this differs from the value taken in °C. In your own words, explain what is meant by the term temperature. Discuss in the group. Write down your opinions.

W2: Without the use of a thermometer, try to determine: the temperature in the room, the temperature of cold and hot water in a beaker, the temperature of the skin on your hand. Why do we need a thermometer to determine the temperature? Discuss in the group. Write down your opinions.

W3: Look at a few types of thermometers that are available. Name them and try to determine how the different types of thermometers can measure temperature (based on what principle influences each of them). Generalise how a thermometer works. Discuss in the group. Write down your opinions.

W4: Observe the Galileo thermometer set up on the table, a thermometer immersed in cold water, and a thermometer submerged in hot water. Try to measure the temperature of each thermometer. How can the Galileo thermometer measure temperature? Based on what principle does it work? Discuss in the group. Write down your opinions.

W5: Check how a buoy behaves in water.

W6: Make buoys measure the temperature even when they are submerged in water.

W7: Verify that the buoy measures a different temperature.

W8: Suggest a procedure for the “warmer” buoy.

From the point of view of self-evaluation, analyse the students’ answers to the questions:

SE1: In today’s activity, Let’s Repair the Broken Galileo Thermometer, I have learnt …

SE2: The most the interesting thing for me during the activity was …
SE3: One question to which I still don't know the answer is …

Table 1
Self-evaluation skills of the student after the activity

RATE THE RESULTS OF YOUR WORK			
After this activity, I know how to...	With considerable assistance	With assistance	Individually
Explain the principle of the functioning of the Galileo thermometer			
Measure the temperature with the help of the Galileo thermometer			
Adjust the buoys so that they can measure the temperature			
Formulate conclusions on the basis of personal observations			

Results

Based on the 461 respondents' answers to the conceptual questions, the self-evaluation and the evaluation of the acquired skills, it is possible to state the following.

Q1 When asked, the students list as examples of a thermometer: mercurial, digital, laboratory, medical and bimetallic. They mention the liquids inside the thermometer, the various metals or the electric current, but the principle of operation is not described. In most cases, the students absolutely do not understand the physical principle (volumetric thermal tensibility, change in the electrical resistance, variation in the length of tensibility). They merely state information about the types of thermometers they can remember, without understanding how they work.

Q2 When the students specify the forces, they make the following mistakes: specifying of forces is completely missing, only the force of gravity is drawn, all of the forces are outside the floating body, the forces affect only the surface of the body at the place of contact with the liquid, the point of affection of gravity and the buoyancy force is the same, the buoyant force effects the bottom part of the body.

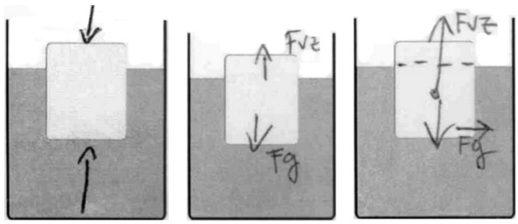

Figure 2. Typical student answers regarding forces acting on a floating body.

Q3 The students have a correct understanding of the comparison of densities between bodies and water.

Q4 None of the answers were correct. The existence of buoyancy forces matches reality; it is described by the fact that a body with lower density will float in a liquid with greater density. Students consider this to be a fact. The mechanism on the basis of which expulsion exists is unknown to them.

We noticed that there were no entries whatsoever on many of the worksheets. In discussions, we found out from the students that writing is done only if their teacher dictates it. The following problems were determined by an analysis of the worksheets: important formulas were missing in the part regarding findings, there was a low level of procedure logging, there was a low level of discussion in groups, the ability to formulate questions separately was weak, and there was a complete absence of arguments. It is clear that the students are not used to producing records from measurements separately. However, our findings could be partially distorted by the informal environment in which the measurements were made.

During the final self-evaluation, the students were asked to state what they had learnt during the day. We expected answers focused on acquired knowledge and skills related to the conducted activity.

SE1 We were surprised by the high percentage of absent answers, despite the free choice of the formulation. From the point of view of acquiring new knowledge, responses are distributed as follows (Figure 3).

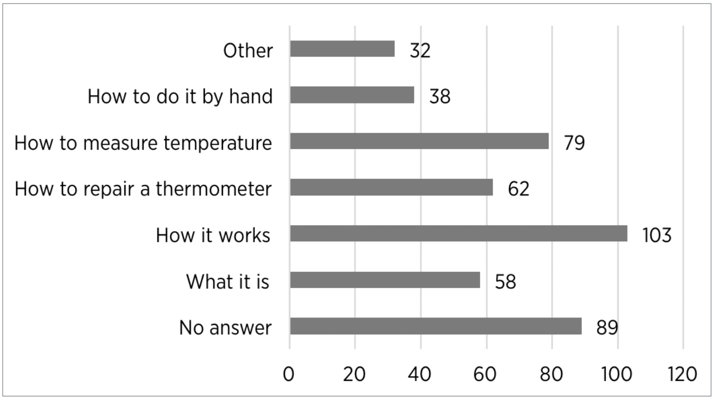

Figure 3. Students' answers related to acquiring knowledge.

At the end of the activity, the students were asked to state what was most interesting for them. The students' responses are compared with our stated educational goals.

SE2 The most interesting aspects for the students were that they were acquainted with a new temperature measuring device, that they could modify the buoys, and that they could work independently.
The answers correspond with our goals.

The questions that remained unanswered were intended to provide an impulse for the revision of the activity, so that it could be renewed or modified in order to eliminate significant deviations from our stated goals.

SE3 We expected the formulation of physical problems related to the measurement of temperature, buoyancy, measuring precision, etc. This revealed the poor ability of students to formulate questions. Interestingly, we received questions such as: What would the ideal weight of the wire for the buoy be? Why do the droplets of liquid have different colours? What is the measuring range of the thermometer?

The answers obtained from the 461 students using the self-evaluation sheet of acquired skills after the completed activity are shown in Table 2. The most common answers are highlighted. The number of correct answers decreases with the increase in the mental difficulty of the evaluated activities.

Table 2
Results of students' self-assessment after the activity

RATE THE RESULTS OF YOUR WORK				
After this activity, I know how to...	No answer	With considerable assistance	With assistance	Individually
Explain the principle of the functioning of the Galileo thermometer	16.3%	9.1%	56.4%	18.2%
Measure the temperature with the help of the Galileo thermometer	13.4%	1.7%	17.6%	67.2%
Adjust the buoys so that they could measure the temperature.	14.8%	30.4%	43.6%	11.3%
Formulate conclusions on the basis of personal observations	16.1%	32.1%	35.8%	16.1%

Discussion

By the end of 2017, we had developed and audited 16 different educational activities organised with the approach outlined above. To date, the activities have been attended by a total of approximately 9,000 students. We are purposefully reaching out to schools in order to repeat their participation in subsequent activities. In most respects, we have made progress in: communication with lecturers, active research, working with worksheets, and providing students with experience in guided inquiry. In addition, we can demonstrate that the safe environment of the Science Centre positively impacts the promotion of the inquiry approach among students, especially during repeated visits to the organised activities. Students feel more comfortable, acquire experience with the task, behave more spontaneously, and achieve better results.

In some instances, the teacher accompanying the students is not a physics teacher. In these cases, there is a drop in the level of influence, as such teachers cannot sufficiently appreciate the benefits of the methodology for active learning. Teachers of physics, on the other hand, are open to constructive criticism. In subsequent activities, they recognise the potential for using what they have seen in the school educational process. They also identify obstacles, such as the lack of technical equipment, the lack of physics lessons in the school curriculum, and the large classes, usually of approximately 30 students. Teachers appreciate the work of the trained and experienced lecturers, which bolsters their self-confidence and their willingness to apply guided inquiry in their own work.

In analysing the work of the lecturers, future teachers of physics, we look for positive feedback on guided inquiry. In particular, they appreciate the interactive discussions and the independent work of student groups, the possibility to select the parts to be used in the activity, the support of students in active research, and the possibility of joint conclusions. In conclusion, we would very much appreciate the opportunity to gain practical experience, particularly thanks to the informal environment of the Science Centre.

Based on our experiences from this activity and with target groups, we introduced an assessment questionnaire in which teachers responded to the following questions (T1 – T7). The questions are teacher-focused, concerning the core elements of our activities, the meaning of the steps and partial tasks, as well as the acquired results. In addition, an interview with experienced teachers was undertaken to obtain a detailed overview of the activity's success.

T1: For the students, the activity was (mark only one option):
a) very interesting
b) interesting
c) somewhat interesting
d) mostly unimpressive
e) unimpressive

T2: In terms of time, the proposed activities in the inquiry science laboratory were:
a) unmanageable in the specified time
b) manageable with an active group of students
c) manageable with a standard class
d) manageable in a shorter interval

T3: Taking into account the level of the students, the prepared worksheet was:
a) very difficult
b) rather difficult
c) adequately challenging/manageable
d) rather easy
e) easy

T4: What relationship does the knowledge of students acquired in school have with the information contained in the activity?
a) The activity complements the material that the students have already learnt.
b) The activity deepens the material that students have already learnt.
c) The activity extends the students' knowledge.

d) Other ......

T5: Do you want to conduct the activity next time? (mark only one option)
a) Yes, I want to conduct the activity in the inquiry science laboratory as a teacher, and I expect only assistance from the lecturer.
b) Yes, I want to actively conduct activities in the lab, but the lecturer should remain as the main presenter.
c) I want the lecturer to lead the activity.
d) Other...

T6: Are you planning to repeat the activity that the students have undertaken in the lab during class in school?
a) Definitely
b) Most likely
c) I haven't decided yet
d) Probably not
e) Definitely not

T7: Are you planning to assess the students for their work in the inquiry science laboratory; for example, based on the worksheet?
a) Definitely
b) Most likely
c) I haven't decided yet
d) Probably not
e) Definitely not

Table 3
Results of teachers' assessment of the inquiry activities

	Teachers' answers				
	a)	b)	c)	d)	e)
T1	42%	42%	16%	0%	0%
T2	4%	19%	77%	0%	-
T3	3%	10%	84%	3%	0%
T4	3%	29%	68%	0%	-
T5	0%	0%	97%	3%	-
T6	49%	32%	10%	3%	6%
T7	10%	13%	26%	32%	19%

We use the same structure of worksheets, the same methods of directed inquiry, the same lecturers, the same time constraints, and the same methods of self-evaluation in every activity. Table 3 shows the responses of 100 teachers who undertook the evaluation of the 16 learning activities. The teachers evaluated the activities as stimulating and manageable with a standard class of students. The level of complexity of the worksheets is appropriate to the students' age range. The available activities are aimed at broadening the knowledge and skills of students, above and beyond school-level physics. Our aim was to motivate the teachers to acquire practical experience in inquiry-based learning, but most of the teachers prefer to leave the task of leading the student groups to the lecturers. The positive impact of the activities in the science centre on its application in the school environment is certainly praiseworthy.

Conclusions

Design-based research was used for the development and evaluation of a new educational activity on the level of guided inquiry. In order to manage guided inquiry, we use topics that are interesting from the point of view of the student, and that could be an educational challenge and a motivation for active research. Students work in groups according to the instructions in the worksheet provided, while trained instructors direct their work. At the end of the activity, the students formulate their findings based on their own measurements. The activities are focused on conceptual understanding and support the development of selected skills. The future lecturers, as well as the teachers following the course of the activity, gain valuable experience in conducting guided inquiry. The group of lecturers share their experiences and suggest improvements to the authors regarding materials and methodology. Once per semester, the whole team focuses on new topics suitable for the next period of training. School groups organised by science teachers are welcome to return to the centre again. If students are involved in guided inquiry activities a few times during their regular school classes, much better interaction during activities is evident and more positive feedback can be achieved. Thanks to the positive examples of the successful implementation of such activities, we are convinced that we are able to support IBSE in schools. However, the problem of educating teachers, their personal attitude towards using inquiry-based learning in their curricula, and the available support in terms of methods and work materials, remains unresolved.

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