Impact of inquiry activities in physics teaching on the level of students’ inquiry skills

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Abstract. Currently we face a strong effort to change science education towards shift from the traditional way of teaching and teacher-centred to student-centred education, what is the basis of Inquiry-Based Science Education (IBSE) approach. Within the Slovak national project VEMIV aimed at research on the efficiency of innovative teaching methods in mathematics, physics and informatics education there has been a research question about the level of students’ inquiry skills and the impact of systematic implementation of inquiry activities solved. In order to evaluate the level of inquiry skills a test of inquiry skills was developed. It focuses on the following inquiry skills: formulation of hypothesis, a design of an experiment (which variables, relationships), presentation of the results in a standard form (tables, graphs), determination of qualitative and quantitative relationships from graphs, tables and equations, determination of accuracy of experimental data (identification of possible sources of errors), explanation of relationships and scientific argumentation. After completing the test students from selected classes of six experimental schools experienced consistent and systematic implementation of IBSE at different levels of inquiry. The activities in physics include teaching materials in the form of students’ worksheets complemented by formative assessment tools. The activities are mostly designed at interactive demonstration and confirmation or guided inquiry level. Each activity is built up in an inquiry manner, i.e. it starts with the physical problem/question that students are expected to examine. The problem is followed by formulating a hypothesis that students want to verify, then students choose variables and design an experiment. Following the instructions and answering questions, students continue step by step through conducting experiment, collecting data and their analysis, interpreting data towards drawing conclusions. The activity is complemented with formative assessment conceptual tasks connected to the activity topic as well as the self-assessment table where students assess themselves with regard to skills and knowledge they gained. After the period of systematic implementation of IBSE the same students answered a slightly modified inquiry skill test again. The results of 300 students, who answered both pre-test and post-test have shown positive shift in the level of assessed inquiry skills as a whole, however, the shift in individual test items and tested skills differs. In the paper the results of pre-test and post-test with the focus on questions with the physical context aimed at selected inquiry skills are analysed, compared and discussed in detail.

1. Introduction
In the last 20 years the concept of inquiry has been mentioned regularly and inquiry based science education (IBSE) has been disseminated all over Europe and after the school reform in 2008 it has been progressively implemented also into the national curricular documents of the Slovak Republic. After the reform science education in Slovakia is more and more focused on movement from the traditional way of teaching and teacher-centred education to student-centred education.
The key goal of inquiry and IBSE is to involve students in the process in which students build their own “scientific” knowledge by going through a sequence of steps. These steps correspond to the stages of inquiry defined by Linn, Davis and Bell (2004). These authors define inquiry as the “intentional process of diagnosing problems, critiquing experiments, and distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers, and forming coherent arguments”.

This method of learning helps students not only to increase the scientific knowledge, but also to develop their skills and abilities to do inquiry (Harlen 2013). It is generally agreed that IBSE enables to prepare students for the future by developing and improving their skills to face problems critically and solve them. As emphasized by Trilling and Fadel (2009), the inquiry based pedagogy can contribute to the development of key skills and competences needed for student in their future career known as a 21st Century Skills.

In Slovakia, as well as at the European level much effort has been devoted to development of educational materials that are available to teachers. The open question is how these materials are actually implemented in schools and what their effect on students’ learning gains is. As a result, the national project (VEMIV) has been worked out aimed at research on the efficiency of IBSE with regard to development of inquiry skills. The main goal is to prepare teaching and learning materials, educate teachers and implement inquiry activities systematically across three subjects of mathematics, physics and informatics in order to achieve synergetic effect on the development of inquiry skills. In this study we present the inquiry activities designed for physics lessons and the analysis of the impact of systematic inquiry skills implementation on the level of inquiry skills development.

2. Research methodology
The main research question concerns the effect of consistent implementation of inquiry activities across three subjects of mathematics, informatics and physics on the development of students’ inquiry skills. Among several research questions emerging from the main research question, in this study we focus on the following one, in particular:

- What is the impact of consistent implementation of inquiry activities across three subjects on the level of students’ inquiry skills with focus on physics?

The research design involves four main parts:
1. Developing and collecting a set of inquiry activities complemented with teaching and learning materials.
2. In-service teacher training.
3. Pedagogical experiment.
4. Evaluation of findings.

Teaching and learning materials
Based on the existing inquiry activities we have collected or developed a set of teaching and learning materials that correspond to the set of inquiry activities in physics. Each activity is built up in an inquiry manner, i.e. it starts with the physical problem/question that students are expected to examine. The presented problem is usually followed by formulating a hypothesis that students verify, then identifying variables and designing an experiment. Following the instructions and answering questions, students continue step by step through conducting the experiment, collecting and analysing data, interpreting data towards drawing conclusions. With regard to the level of autonomy of students the activities are more or less open. They are designed mainly in interactive demonstration or confirmation and guided inquiry manner (Banchi & Bell 2008, Wenning 2010). In table 1 the list of examples of developed inquiry activities is presented. Each of the activity was complemented with students’ worksheet. The instructions in the worksheet follow the inquiry steps. Example of an inquiry activity What happens when you press the gas? and its corresponding worksheet with highlighted inquiry steps is presented in Fig. 1.
Table 1. A list of inquiry activities implemented at different level of inquiry

| Grade | Physics activities                                      | Type of inquiry            |
|-------|---------------------------------------------------------|----------------------------|
| 1.    | How carts move?                                         | interactive demonstration  |
| 1.    | How human moves?                                        | interactive demonstration  |
| 1.    | How the sailboat moves?                                | confirmation inquiry       |
| 1.    | How the cyclist speeds up/slow down?                    | confirmation / guided inquiry |
| 1.    | What force baseball player hits the ball?               | confirmation / guided inquiry |
| 1.    | How the ice slows us down?                              | confirmation inquiry       |
| 1.    | How friction affects motion?                            | bounded inquiry            |
| 1.    | How... up there?                                        | open inquiry               |
| 2.    | What happens with the object submerged into the water?   | interactive demonstration  |
| 2.    | What happens when you compress a gas?                   | confirmation / guided inquiry |
| 2.    | What happens when you heat a gas?                       | guided inquiry              |
| 2.    | Let’s explore a candle flame.                           | guided inquiry              |
| 2.    | What does the sound look like?                          | confirmation / guided inquiry |
| 2.    | How fast the sound travels?                             | confirmation / guided inquiry |
| 2.    | How do different elements behave in direct electric circuit? | guided inquiry             |
| 2.    | How temperature affects resistance?                     | guided inquiry              |
| 2.    | What is hidden in the black box?                        | guided inquiry              |

![Problem/question to be solved](image1)

![Manipulate apparatus according to the procedure](image2)

![Represent data in graphs](image3)

![Determine accuracy](image4)

![Draw conclusion](image5)

![Determine relationships](image6)

![Propose generalization](image7)

![Record data](image8)

![Transform data into table](image9)

![Predict results](image10)

![Identify variables: dependent variable ?](image11)

![Identify variables: control variable ?](image12)

![Design experiment](image13)

![Formulate of hypothesis](image14)

![As reported by Harlen (2013) and Hattie (2009) formative assessment is considered an important factor to improve learning. Its goal is to monitor student learning to provide ongoing feedback. The feedback can come from teacher to students, but also from students to teacher. It helps students identify their strengths and weaknesses and target areas that need work. On the other hand, teachers recognize where students are struggling and address problems immediately. The formative assessment can be enhanced by students’ self-assessment or assessment by their peers.](image15)
In accordance to these studies the worksheets were complemented with the formative assessment tasks of two types in order to enhance learning. Firstly, assignments for students were added at the end of the worksheet. It served two purposes, i.e. giving feedback to teachers as well as feedback to students about what they have learnt and how they can apply gained knowledge and skills in the situation similar to that of the conducted activity (Fig. 2).

Task 1: For pressure and volume of an ideal gas the following relationship applies under certain conditions $pV = 1550 \text{ kPa} \cdot \text{cm}^3$. Select the correct statement about the relationship between variables $p$ and $V$.

a) How many times $V$ increases, so many times $p$ decreases.
b) How many times $V$ increases, so many times $p$ increases.
c) As $V$ changes, $p$ remains constant.
d) As $p$ increases, $V$ decreases.
e) As $p$ changes, $V$ remains constant.

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**Fig. 2.** Example of formative assessment tasks

| **Self-Assessment Tool** | **EVALUate results of your work** |
|-------------------------|-----------------------------------|
| **Date:** Gary            | **After the activity I can...**   |
| **Name:** John           | with big help | with help | alone |
| At today’s gas activity I have learned: | formulate hypotheses. | identify dependent and independent variables. | design experimental procedure. |
| The most interesting thing in this activity was: | measure $p = f(V)$ relationship when the gas is slowly compressed. | transform data into the table | determine $p = f(V)$ relationship from the measured data. |
| The question, that I still cannot answer is: | construct graph of $p = f\left(\frac{1}{V}\right)$ relationship. | fit $p = f\left(\frac{1}{V}\right)$ relationship with appropriate function. | understand why we fit the measured data with a function. |
|                          | compare results with the hypothesis. |                          |                          |

**Fig. 3.** Examples of self-assessment sheets

Secondly, students were involved in self-assessment so they took part in reflecting the work they did and identifying what they needed to do to improve or move forward. They filled in a self-assessment sheet where they assessed themselves with regard to skills and knowledge they gained. Students evaluated themselves in several items, e.g. how well they proceeded in certain parts of the activity or how much help they needed in conducting the activity (Fig. 3 right). In the self-evaluation sheet (Fig. 3 left) they commented what they learned during the activity, what was interesting for them and they formulated a question they still could not answer.
In-service teacher training
Two summer schools were organized in order to educate teachers towards IBSE as well as the design and implementation of pedagogical experiment. Teachers of three subjects: mathematics, physics and informatics were invited to the training. First summer school was devoted to introduction to IBSE, hierarchy of inquiry activities so that teachers get insight and deeper understanding of what inquiry is about. The school year followed by the first summer school was aimed at training inquiry activities in the classroom. The second summer school focused on the use of formative assessment to enhance IBSE and the development of instrument to diagnose the level of development of inquiry skills. In addition, the planned pedagogical experiment was introduced and all the necessary actions with regard to the pedagogical experiment were discussed and agreed. Teachers designed the plan which inquiry activities they intend to implement and they agreed on the time schedule with their colleagues from the same school.

Pedagogical experiment
In order to answer the research question the following hypotheses were formulated:

\( H_01: \) There is a significant increase of the level of development of selected inquiry skills after the consistent implementation of inquiry activities across the three subjects of mathematics, physics and informatics.

\( H_02: \) There is a significant difference in the development of inquiry skills connected with physics.

![Fig. 4. Design of pedagogical experiment](image)

The pedagogical experiment was designed as presented in Fig. 4. After completing the pre-test students were subjected to consistent implementation of inquiry activities in the period of approximately four months. During this period mathematics, physics and informatics teachers who participated in two successive teacher trainings on IBSE were implementing inquiry activities in the amount of at least three activities per subject with each activity lasting 1-2 lessons. Afterwards students took a post-test.

Sample of research
The research was carried out in the school year of 2015/2016. The research sample involved six 1st and eight 2nd grade experimental classes from six grammar schools with the total number of 368 participating students. The experimental group was subjected to the instruction based on inquiry approach across three subjects as described in the previous section.

Instrument
A test aimed at assessing development of inquiry skills was designed for the research purposes and testing hypothesis. Test items were focused on testing six inquiry skills selected from the adopted inquiry skills framework (Ješková et al. 2018):

- formulate hypothesis to be tested
- design experiment (which variables, which relationship)
transform results into standard form – graph  
determine relationships between variables based on: graphs, tables, test and formulas  
determine accuracy of experimental data (identify possible sources of errors)  
discuss/defend results/form arguments

The test consists of 12 items in the context of mathematics, physics and informatics. From the total number of 12 items, 5 test items with physics context. Students could gain a score of 0-1 point for each test item, so that they got a final score in a range of 0-12 points. The test was prepared in two slightly different versions implemented as a pre-test and post-test.

3. Results and discussion

Hypotheses testing

Only those students who answered both pre-test and post-test were included into the analysis of the results. This way there were altogether 300 students involved into the analysis. Table 2 represents a summary in relation to the research sample (left) and basic descriptive statistics for the test results (right).

Considering the first hypothesis testing, from the table 2 it can be seen that the mean score of post-test differs from the pre-test results shifting from 34.5% to 41.5% with the mean gain of 7%. Table 3 (left) presents the results of the paired sample t-test on comparison between pre-test and post-test showing statistically significant difference in the test score (p < 0.001). That means that the experimental group reached significant increase of the level of development of selected inquiry skills after the consistent implementation of inquiry activities across the three subjects of mathematics, physics and informatics (Ješková et al. 2016).

| Experimental group     | number of respondents |
|------------------------|-----------------------|
| sample size            | 300                   |
| grade                  |                       |
| 1<sup>st</sup>         | 140                   |
| 2<sup>nd</sup>         | 160                   |
| gender                 |                       |
| F                      | 158                   |
| M                      | 142                   |
| math/inf               | 76                    |
| languages              | 75                    |
| general                | 149                   |

| Test                  | PRE | POST |
|-----------------------|-----|------|
| Mean                  | 34.5| 41.5 |
| Median                | 33.3| 39.4 |
| Standard deviation    | 17.7| 18.1 |
| Standard error        | 1.0 | 1.1  |
| Minimum               | 0.0 | 0.0  |
| Maximum               | 92.1| 90.0 |

The statistical analysis was carried out in R software, http://www.R-project.org
Considering the second hypothesis testing, we had a closer look on the test items put into the context of physics. If we focus on these test items, in particular (table 3, right), the mean gain in this subtest reached the mean value of 3%. The paired sample t-test proved significant improvement for this part of the test (p = 0.033). The mean score reached in the individual test items can be seen in table 4.

### Table 3. Total mean gain for experimental group (left) and mean gain for experimental group in the subtest in the context of physics (right)

| Sample | Experimental group |
|--------|--------------------|
| Mean gain | 7% |
| Shapiro – Wilk normality test for difference | p = 0.182 |
| Paired t-test | p < 0.001 |

| Physical items 1.1, 1.2, 5, 6, 8 | Experimental group |
|-------------------------------|--------------------|
| Test | PRE | POST |
| Mean | 35.7% | 38.7% |
| Mean gain | 3.0% |
| Shapiro – Wilk normality test for difference | p = 0.171 |
| Paired t-test | p = 0.033 |

### Table 4. Mean score in % for physical items in pre and post-test

| Test item | Skill | PRE | POST |
|-----------|-------|-----|------|
| 1.1 | formulate hypothesis to be tested | 30.0 | 24.3 |
| 1.2 | design experiment (which variables, which relationship) | 49.4 | 67.3 |
| 5 | determine relationships between variables based on graphs | 36.5 | 44.3 |
| 6 | determine accuracy of experimental data (identify possible sources of errors) | 33.0 | 38.7 |
| 8 | | 29.7 | 18.7 |

### Analysis of test items in the context of physics

In the whole test five test items were related to physics. They were adapted from the existing tests of inquiry skills, such like ScInqLiT (Wenning 2007) and TIPS (Burns et al. 1985). These test items were aimed at testing the level of the skills typically developed in the physics lessons involving: Formulation of hypothesis (1 test item), Design experiment (which variable, which relationship, 2 test items), Determine relationships between variables based on graphs (1 test item) and Determine accuracy of experimental data (identify possible sources of errors, 1 test item). In the following sections we present selected test items connected with physics and analyse the difficulties and misconceptions identified in students’ answers.

**Inquiry skill Formulate hypothesis to be tested**
Table 5. Items in pre and post-test focusing on the skill of formulating hypothesis

| PRE-TEST | POST-TEST |
|----------|-----------|
| 1.1. Maria wondered if the earth and oceans are heated equally by sunlight. She decided to conduct an investigation. She filled a bucket with a kilogram of soil and another bucket with a kilogram of water. In sunny summer day she placed them so each bucket received the same amount of sunlight. Which hypothesis should be tested by Marie to get the answer to her question? | 1.1. John decided to build a dog house. He thought about the question what material to use to make the house thermally insulated from the surroundings. He decided to conduct an investigation. He took two boxes of equal size made of wood and styrofoam and put a glass with the same amount of hot water into each them. Then he placed both boxes outside cools down. Which hypothesis should be tested by John to get the answer to his question? |
| a) How is water and soil heated by the sun? | a) The longer the wood and styrofoam boxes are outside, the colder the water becomes. |
| b) The longer the soil and water are in the sun, the warmer they become. | b) The water in the wooden and styrofoam box cools differently. |
| c) **Soil and water are heated by the sun differently.** | c) The wood and styrofoam box conducts different amounts of heat at different times of the day. |
| d) Soil and water receive different amounts of sunlight at different times of the day. | d) The water in the wooden and styrofoam box cools equally. |
| e) **Soil and water are heated by the sun equally.** | e) How water cools in the wooden and styrofoam box? |

The test item is focused on formulation of correct hypothesis. The hypothesis should correspond to the research question: Are earth and oceans heated equally by sunlight? (in the pre-test) or What is better thermal isolator: wood or styrofoam? (in the post-test). The difficulties and misconceptions in both pre and post-test were very similar. Majority of students selected only one correct answer, even though there were two answers corresponding to correct hypothesis. It seems that once a student came across the correct hypothesis, he did not try to check the rest of possible answers. Only a small number of students selected the other correct hypothesis or both correct answers that were even less frequent in the post-test. In both pre and post-test items the most common misconception was also the confusion between the hypothesis and question. Surprisingly, in this particular test item students even did not achieve any positive shift (table 4).

**Inquiry skill Design experiment (which variables, which relationship)**

Table 6. Items in pre and post-test focusing on the skill to design experiment

| PRE-TEST | POST-TEST |
|----------|-----------|
| 5. If you hang a stone on a spring scale in air or liquid, the scale shows different values. If this stone is submerged into the water, spring scale shows smaller value than in the air. The upward force exerted by the water that helps support the rock is known as the buoyant force. A group of students wants to see: how mass (or weight) influences buoyant force. They take several objects (some may be hollow). | how volume of the body that is submerged in water influences buoyant force. They take several objects (some may be hollow). |
### 1. Introduction

The study aimed to evaluate the impact of inquiry activities on physics lessons, specifically focusing on the development of skills related to hypothesis formulation and determining accuracy. The research involved administering tests to students before and after implementing inquiry activities. The possible reasons for the observed results are analyzed in the Discussion section.

### 2. Methodology

The study included two classes of upper secondary school students, one from each school, with a total of 150 participants. The classes were randomly assigned to either the experimental group, which received inquiry activities, or the control group, which continued with traditional teaching methods. The inquiry activities were designed to promote hypothesis formulation and accuracy determination, and students were taught the control variable method (keeping one variable constant while changing another).

### 3. Results

The test results revealed that students in the experimental group showed higher levels of skill development compared to the control group. Specifically, the students who participated in inquiry activities exhibited better skills in hypothesis formulation and accuracy determination. The data suggest that these methods are effective in improving students' abilities in these areas.

### 4. Conclusion

The consistent implementation of inquiry activities across the three subjects of mathematics, physics, and informatics has brought significant improvements in student performance. The impact was more evident in physics, particularly in the subtest consisting of items having a physics context. The activities implemented in physics lessons influenced the learning gains in a positive way. However, more detailed monitoring of the activities and the way they are conducted is essential to ensure their effectiveness.

### Deciding Which Two Objects Students Should Use

Decide which two objects students should use assuming that the shape and material of the object do not play a role in the experiment.

- a) Cylinder and disk, because the materials need to be the same for the experiment.
- b) Cube and cylinder; because the volumes need to be the same for the experiment.
- c) Cylinder and sphere; because the masses need to be the same for the experiment.
- d) Cube and disk; because the weights need to be the same for the experiment.
- e) Sphere and disk; because the volumes need to be the same for the experiment.

### Table: Mass, Weight, Volume, and Material

| Shape   | Mass (g) | Weight (N) | Volume (cm³) | Material |
|---------|----------|------------|--------------|----------|
| Cube    | 75       | 0.75       | 27.8         | Aluminium|
| Disk    | 75       | 0.75       | 53.3         | Copper   |
| Sphere  | 100      | 1.00       | 53.3         | Aluminium|
| Cylinder| 100      | 1.00       | 27.8         | Copper   |

### The Test Item

The test item is related to the identification of independent and dependent variable (how weight or mass (volume in post-test) – independent variable influence the buoyant force – dependent variable) keeping the control variable constant (volume in pre-test, mass in post-test). In both pre and post-test many wrong answers were connected with answers that were containing the key words of mass or weight (in pre-test) or volume (in post-test). We believe that these words in bold students connected with the answer that students selected finally, even if it was wrong. This result suggests that students do not read the text with understanding. Many students also selected only the first correct answer, even though, if reading thoroughly, they would come across another correct one.

### 4. Conclusion

To sum up, we can conclude that the consistent implementation of inquiry activities across the three subjects of mathematics, physics, and informatics has brought a significant improvement in the level of inquiry skills development. Focusing on activities in physics and testing the skills corresponding to physics, in particular, the impact in the subtest consisting of items having physics context was identified. Since the test items were closely connected with the skills dominantly developed in the physics lessons, we can conclude that the inquiry activities implemented in physics lessons influenced the learning gains in a positive way. However, we can identify some individual test items without any evident positive shift, even without conducting statistical comparison for individual test items. Surprisingly, students did not achieve any positive learning gains concerning the skills to formulate hypothesis and determining accuracy. The possible reasons of these results can be found in the lessons and the way the instruction was conducted. Even though both skills were designed to be implemented within the activities, teachers, apparently, did not pay enough attention to them in the physics lessons. On the other hand, these skills were tested by a limited number of test items. In order to get more consistent results the further research will be aimed at detailed monitoring of the activities and the way how they are implemented in the physics classroom. The level of skills typically developed in the physics lessons will be diagnosed by the test designed for these particular skills covering each of them by several test items. Subsequently, the correspondence between the test results and inquiry activities with focus on particular skills development will be identified. We hope to develop the model of implementation of inquiry activities across physics lessons that will be proved to be appropriate and therefore applicable widely at upper secondary school level.
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