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EFFICACY OF INQUIRY-BASED LEARNING IN MATHEMATICS, PHYSICS AND INFORMATICS IN RELATION TO THE DEVELOPMENT OF STUDENTS´ INQUIRY SKILLS

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Abstract. *The current initiatives at European level urge more emphasis on the implementation of inquiry-based science education (IBSE). Although there are existing studies on the effect of IBSE on understanding science, fewer attempts have been made regarding the development of various inquiry skills. In this research, a model of consistent implementation of inquiry activities across the three subjects of mathematics, physics and informatics was developed and its efficacy with regard to selected inquiry skills development was examined. In order to evaluate the efficacy, a test assessing the level of inquiry skills development was designed. This test was taken by 300 high school students both before and after experimental teaching. In between students were exposed to coherent and intentional multidisciplinary inquiry-based learning within a period of approx. four months. The results showed a statistically significant increase on test scores that is gender independent, however the class specialization played a significant role. The results indicate that the designed model of coactive IBSE implementation is efficacious for inquiry skills development and therefore applicable in school practice.*

Key words: *inquiry skills assessment, inquiry-based science education, inquiry skills, test of inquiry skills.*

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Introduction

The current initiatives in Europe actively pursue the renewal of science education through inquiry-based methods. As proclaimed in the report published by the European Commission (Rocard, Csermely, Jorde, Lenzen & Walberg-Henriksson, 2007), there is firm evidence that indicates a connection between attitudes towards science and the way how science is taught. In contrast to the deductive approach traditionally used in science education, the inductive approach gives more space to observation, experimentation and the teacher-guided construction by the child of his/her own knowledge. This approach in science is most often referred to as Inquiry-based science education (IBSE) and is nowadays considered one of the most effective ways to improve science education (Rocard, et al., 2007; Cavas, 2012). The inquiry strategies are nowadays in focus of not only science but also other disciplines, like mathematics and even informatics. Rasmussen and Kwon (2007) emphasize that in mathematics education inquiry serves to empower learners to see themselves as capable of reinventing mathematics and to see mathematics itself as a human activity. Hu and Shepherd (2013) and Kussmaul (2012) have developed guided inquiry activities aimed at discovery and understanding of programming concepts by the method of Process Oriented Guided Inquiry Learning (POGIL) and they stressed its potential for informatics education. In the following text, when talking about IBSE, inquiry-based education in science, mathematics and informatics will be meant.

There are many definitions what is meant by inquiry (NRC, 1996; Linn, Davis & Bell, 2004; Llewellyn, 2002). With regard to the definition by Linn,

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Davis and Bell (2004), inquiry is 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. In brief, inquiry is a process by which students actively investigate their world through questioning and seeking answers to their questions. As similar to science, students´ investigation can be carried out either through active experimentation or by modelling the behaviour of an object or a system. The latter one can be referred to as model-based inquiry (Cheng, Lin, Chang, Li, Wu, & Lin, D., 2014). During the process of investigation the student is given less or more autonomy so that the inquiry encompasses a range of levels depending on the degree of intellectual sophistication and locus of control (Wenning, 2010) from strictly teacher-directed up to student-directed open inquiry (NRC, 2000). Inquiry in schools is influenced by educational needs and constraints such as learning scaffolds or selecting investigations that students are likely to master (Emden & Sumfleth, 2016). It is generally agreed that IBSE focuses not only on knowledge but it also involves the process of constructing knowledge corresponding to the stages of inquiry described in the definition (Linn, David & Bell, 2004). As a result, in addition to knowledge acquisition and its understanding, IBSE strongly emphasizes the development of skills and abilities to conduct inquiry.

Much effort has been already put into the research on the impact of IBSE on the level of understanding science (Kane, 2013; Chinn & Malhotra, 2002; Geier, Blumenfeld, Marx, Krajcik, Fishman, Soloway & Clay-Chambers, 2008; Wilson, Taylor, Kowalski & Carlson, 2010; Blanchard, 2010; Anderson, 2016). However, fewer attempts have been made regarding the effect of IBSE on the development of various inquiry skills (Wenning, 2007; Gormally, Brickman, Hallar & Armstrong, 2009; Marx, Blumenfield, Krajcik, Fishman, Soloway, Geier & Tal, 2004; Pešaković, Flogie & Aberšek, 2014; Emden & Sumfleth, 2016).

Nevertheless, the existing research in the field of IBSE has been dominantly conducted within a subject of either physics, chemistry, biology or integrated science. On the other hand, there is much less experience with inquiry implemented in mathematics and in informatics, in particular, even though there is potential for students to do inquiry within these subjects. Moreover, the existing studies do not reflect on the effect of consistent implementation of IBSE across several disciplines. That is why this aspect was decided to be focused on respecting tight interdisciplinary connections between physics, mathematics and informatics. Therefore, this research was conducted examining how consistent implementation of inquiry activities across these three subjects can facilitate development of students´ inquiry skills.

Inquiry and Inquiry Skills Development

Having a closer look at what skills and abilities are in focus of IBSE, different frameworks can be found. One approach is based on the inquiry process and the skills that correspond to its different stages (Fradd, 2001; Wenning, 2007), while the other is based on the level of sophistication (Wenning, 2010) with regard to age group (NRC, 2000). On the basis of inquiry skills taxonomies (Fuhrman, 1978; Tamir & Lunetta, 1981; Fradd, 2001; Van den Berg, 2013), a framework for experimentation has been elaborated (Balogová & Ješková, 2016, table1). Not all inquiry activities are necessarily experimental. Therefore, the framework has been modified for the inquiry activities based on modelling (Tran & Van den Berg, in press). The modelling approach is used not only in science (modelling physical, chemical or biological phenomena) but it is dominantly used while implementing IBSE in mathematics education (Kaiser, Blum, Ferri & Stillman, 2011).

As can be seen from the framework (table 1) and also pointed out by Rankin (2000, as cited in Wenning, 2011), teachers need to be aware of the fact that much of the inquiry process occurs both before "doing" a lab, as well as after. The actual hands-on components are not always the most important parts. Moreover, the activities can differ regarding the amount of learner self-direction and direction from teacher or material (NRC, 2000, p. 29). This means that not all skills are necessarily used in any one inquiry activity (Wenning, 2011). As a result, based on the learning goals, the activity can be targeted on the development of particular inquiry skills. E.g., when a question is provided by the teacher and students are even given data to analyse, the emphasis is on the development of skills connected to analysis and interpretation or communication. In another case, the activity can be focused on the skills connected to implementation and collecting data from an experiment.

Table 1. Framework of inquiry skills for experimental activities.

1.Conception, planning and design	1.1. Formulate a question, define a problem. 1.2. Formulate hypothesis or expectation to be tested. 1.3. Design experiment (which variables, which relationship). 1.4. Design observation and/or measurement procedures (incl. lab-apparatus selection; experiment set-up) for each variable. 1.5. Predict results of experiment.
2.Implementation	2.1. Manipulate apparatus/ software. 2.2. Observe/ measure. 2.3. Record results. 2.4. Calculate during the execution. 2.5. Explain or make decisions about experimental techniques.
3.Analysis and interpretation	3.1. Transform results into standard form (i.e. tables, graphs). 3.2. Determine relationships between variables based on e.g. graphs, tables, text and formulas. 3.3. Determine accuracy of experimental data (identify possible sources of errors). 3.4. Compare experimental data to the hypothesis/ expectation. 3.5. Discuss limitations/assumptions of the experiment. 3.6. Propose generalizations of experiment results. 3.7. Formulate new questions/ problems. 3.8. Draw conclusion.
4.Communication	4.1 Share and present results in front of the class. 4.2 Discuss/defend results/form arguments. 4.3 Elaborate formal report about the gained results.
5.Application and follow-up	5.1. Predict on the basis of obtained results. 5.2. Formulate hypothesis for follow-up. 5.3. Apply experimental technique to a new problem.

The existing studies in the field of inquiry skills show insufficient level of their development (Germann & Aram, 1996; Kask & Rannikmäe, 2006; Rollnick, Zwane, Staskun, Lotz & Green, 2001; Hart, Mulhall, Berry, Loughran, & Gunstone, 2000). Similar results can be found in the international survey PISA (Programme for International Student Assessment) where the level of science and mathematics literacy is assessed regularly. Results of PISA 2012 testing show that EU as a whole is seriously lagging behind in the area of mathematics. Progress in science is on track, however, the current reality is that more than 20% of young Europeans do not reach a minimum level of basic skills in mathematics and science (European commission, PISA 2012). The results of testing of Slovak 15 year old students show low level of achievements when working with tables and graphs, interpreting data presented in graphs and identifying and understanding of relationships between variables (PISA Slovakia, 2012).

These results showing low level of development of students´ inquiry skills make us believe that students are not involved regularly in inquiry activities that is an inevitable assumption for the development of science process skills, in particular. As reported by Anderson (2002), the main barrier in successful implementation of IBSE is connected to the teacher and lack of his pedagogical content knowledge. Several other studies (Welch, Klopfer, Aikenhead, & Robinson, 1981; Eltinge & Roberts, 1993) offer the following suggestions as to why teachers do not use IBSE: lack of training, lack of time, lack of materials, lack of support, overemphasis on assessing content learning rather than process learning, inquiry approach is too difficult and much more time consuming. The critical element for carrying out inquiry in the classroom is the teacher who must change his knowledge, beliefs and skills to adopt inquiry-based approaches. The importance of teaching materials is also considered an important assumption for successful implementation of IBSE.-

Considering the above-mentioned studies, in this research, the focus is on the consistent inquiry-based approach to teaching three subjects conducted by teachers trained for IBSE who are provided with inquiry oriented teaching materials. This way a synergetic effect of multiple implementations of inquiry activities in one classroom is expected to be achieved.

As a result, the main research aim is to develop a model of coherent and intentional multidisciplinary implementation of inquiry activities across the three subjects of mathematics, physics and informatics and to find out whether the developed model applied in a classroom is efficacious in relation to the selected inquiry skills development. With regard to the main research aim the following research questions were defined:

What is the initial level of selected inquiry skills´ development of the research sample?

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Is the developed model of implementation of inquiry activities applied in teaching efficacious with regard to the selected inquiry skills' development?

How do different factors (class specialization, gender and grade) affect the efficacy of the model of implementation of inquiry activities with regard to the selected inquiry skills' development?

Inquiry skills selected to be in the main focus of this research are marked bold in table 1 and commented in the following sections.

Research Methodology

Research Design

As discussed in previous sections, it is agreed that the successful implementation of IBSE depends on the teacher and availability of teaching materials. That is why these issues were addressed before searching for answers to the research questions.

Firstly, activities based on IBSE approach were developed. They involved a collection of inquiry activities for teaching mathematics, physics and informatics including materials for teachers (teachers´ guide with detailed comments), students' worksheets and other additional materials (computer files or other teaching aids). It has been well-known for a long time that digital technologies play an important role to effectively enhance inquiry in the classroom (Heck & Ellermeijer, 2014; Newton & Rogers, 2001; Novak & Krajcik, 2004; Tamin, Bernard, Borokhovski, Abrami & Schmid, 2011; Koyuncu, Akyuz & Cakiroglu, 2015). Therefore, in the majority of activities digital tools are applied in order to collect, process and evaluate data. The activities are developed in a more guided inquiry manner, mainly confirmation or guided inquiry or interactive demonstration. This was agreed respecting the results of several researches showing that more open inquiry-based instruction is less effective than more guided forms of inquiry-based instruction (Kirschner, Sweller & Clark, 2006; Klahr & Nigam, 2004).

Considering the content, in mathematics the activities cover the topic of divisibility, planimetry and functions. In divisibility the main goal is to search and discover the criteria of divisibility by number 11. In planimetry the focus is on the properties of a triangle midsegment and the centre of mass of a triangle. Considering functions, the properties of different types of functional dependencies focusing on graphs, monotonicity of functions and properties of inverse functions were explored. The investigations were carried out in Geogebra computer learning environment that enables students to understand connections between representations, construct hypotheses and build explanation for the observed patterns (Hohenwarter & Preiner, 2007).

In physics, the activities concern motion, ideal gas properties, sound and electric circuits. In motion, the focus was on the investigation of different kinds of motion using video-analysing tools (e.g. how a cyclist moves, what force acts when hitting a ball, how friction influences motion). Students were also discovering the ideal gas laws, exploring basic properties of sound, behaviour of different elements in an electric circuit or influence of temperature on electric properties of circuit elements. All these inquiry activities were supported by computer tools (sensors, video-analysing tools, tools for data processing and analysis) of COACH learning environment (Heck, et al., 2014).

In informatics, the activities involve data encoding and compression, communication protocols and mobile devices programming. In the activities students were exploring and discovering basic principles of effective encoding and its application in everyday life. The other types of activities were focused on the inquiry process using e.g. the example of black box content exploration with the help of appropriate problem solving strategies.

In table 2 there are examples of implemented inquiry activities. The "++" symbols designate the skills from the inquiry skills' framework (table 1) that are in the main focus of the activity.

Table 2. Examples of implemented inquiry activities with focus on selected inquiry skills from the framework in table 1.

1.2	1.3	1.4	1.5	2.1	2.2	2.3	2.4	3.1	3.2	3.3	3.4	3.5	3.6	3.8	4.2
Why are some identification codes divisible by number 11?															
+		+		++	+	+		++	++				++	+	++
What are the properties of the centre of mass of a triangle?															
++	+	+		++	++	+	+	+	+	+	+		++	+	++
How to distinguish quadratic function from other functions?															
++		+	+	+	+	+	+	++	++		+		++	+	+
How does the baseball player hit the ball?															
	++		+	+	+				++	+	+			+	+
What happens when we compress air?															
++	++	++	+	+	+	+		+	++	+	+	+	+	+	+
How do different elements behave in direct electric circuit?															
+	++	+	+	+	+	++		+	++	+	+		+	+	+
How effectively encode properties of objects using a binary number system?															
+						++		+	++		+		++	++	++
What compression ratio can be achieved according to chosen graphical formats and content of an image?															
++	+		++		+	+	+	+	++		+		++	+	+
Can we determine an exact rule for an unknown system based on given pairs of its inputs and outputs?															
++	+		+	+	+	++		+	++		++	+	++	++	++

Next, six high schools were selected from which mathematics, informatics and physics teachers agreed to cooperate. These teachers participated in a teacher educational programme (TEP) focused on IBSE. One of the TEP key goals was a co-ordinated training when different subject teachers from the same school communicated and cooperated intensively during the training course. This approach should have ensured the later consistent implementation of IBSE across three subjects supported by mutual teachers´ cooperation.

TEP was conducted in two successive cycles. The first teacher summer school was aimed at IBSE, its principles and goals. Teachers working in the role of students carried out inquiry activities in order to understand the inquiry learning scenario. The goal of the training was also to develop skills to manipulate computer tools that were used to enhance inquiry activities. In the following school year teachers were trialling activities in the classroom. Based on the questionnaires answered by teachers the inquiry activities were modified. The second summer school discussed the results and experience from the trialling and prepared the upcoming pedagogical experiment. Teachers also took part in the development of an assessment instrument for evaluating the level of inquiry skills resulting in the first version of the test. This test version was later modified on the basis of pilot testing in selected classes in order to develop the final version of pre-test and post-test. All the steps described above belonged to the preparatory phase of the research (see figure 1, up).

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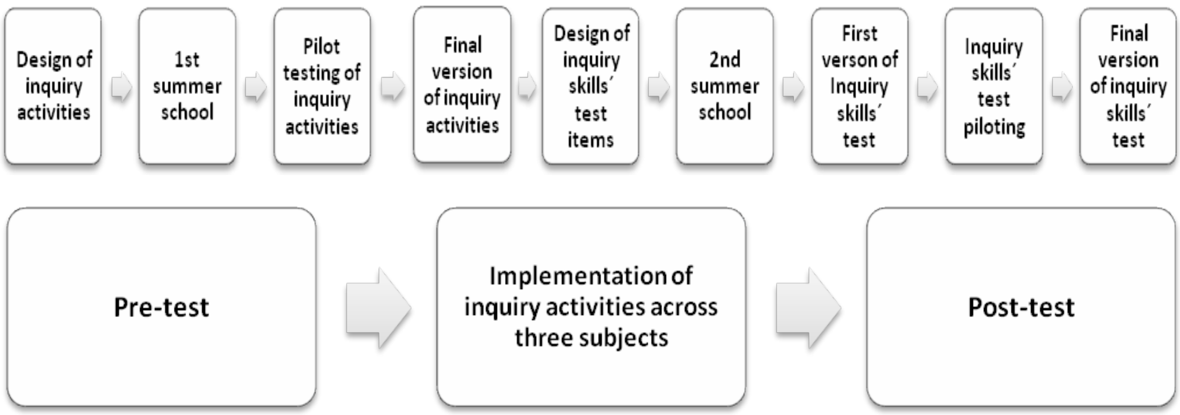

Figure 1: Research design (preparatory phase and pedagogical experiment).

The preparatory phase (2014-2015) was followed by the pedagogical experiment (school year 2015/2016). At the beginning, students participating in the research took a pre-test in order to assess their initial level of development of selected inquiry skills. Neither teachers, nor students were acquainted with the pre-test results in order to avoid influence of possible communication on the post-test results. Subsequently, the students were subjected to the experimental instruction within a period of approx. four months. During this period teachers applied the designed model of IBSE implementation. Teachers were expected to select and implement at least three activities per subject with each activity lasting 1-2 lessons. As a result, students were exposed to coherent and intentional multidisciplinary inquiry-based learning conducting inquiry activities in mathematics, physics and informatics lessons. Examples of performed activities are presented in table 2. After that students took post-test in order to evaluate the learning gains.

Research Sample

The pedagogical experiment for reaching the research aim started in the autumn 2015 at six high schools on the basis of quasi-experimental design (Cohen, Manion & Morrison, 2007). Six participating schools were agreed as a reasonable number for effective research management. Fourteen classes were intentionally selected where the model of consistent implementation of inquiry activities was applied by teachers who took part in IBSE teacher training. In order to answer all the research questions, the classes were selected on the basis of grade and class specialization. As a result, there were six 1st grade classes (students aged 15-16) and eight 2nd grade classes (students aged 16-17). They belonged to one of three streams with focus on foreign languages (4 classes), mathematics or informatics (4 classes) or the stream with no special focus (6 classes). Altogether the classes involved 368 students and 27 teachers participating in the experiment.

Research Hypotheses and Instruments

From the research questions the following hypotheses emerged.

1. H_{01}: There is a significant difference between the initial level of selected inquiry skills and the level of selected inquiry skills after a period of the consistent implementation of inquiry activities across the three subjects of mathematics, physics and informatics.
2. H_{02}: There is a significant difference between students grouped according to agreed criteria (class specialization, gender and grade) in difference between the initial level of selected inquiry skills and the level of selected inquiry skills after a period of consistent implementation of inquiry activities across the three subjects of mathematics, physics and informatics.

The model of consistent implementation of inquiry activities across the three subjects of mathematics, physics and informatics is described in the research design section.

For testing the hypotheses there was a need to have an instrument to assess the level of students´ selected inquiry skills. Development of an inquiry skills´ assessment instrument has already been in focus of several researchers. Nevertheless, most such instruments had limitations. Alonzo and Aschbacker (2004) designed performance-based assessments that took over 2.5 hours to conduct all the laboratory tasks. On the other hand, Wenning (2007) designed a paper-pencil test consisting of 40 multiple-choice items (ScInqLiT). This test and also other available multiple-choice tests (TISP, Burns, Okey & Wise, 1985; TOSLS, Gormally, Brickman & Lutz, 2012) are very extensive and hence time-consuming with items related mainly to physics, biology or chemistry, not the context of mathematics or informatics. Shorter TGSA test (Zion, Michalsky & Mevarech, 2005) consisting of 15 binary scored multiple-choice items assesses general scientific abilities related to biology. Since there was no suitable assessment instrument of reasonable extent and content feasible for classroom use available, finally, a test for the purpose of this research has been developed.

The framework in table 1 was used to specify what is to be measured. From this framework only those skills were selected that were in dominant focus of inquiry activities performed during IBSE implementation and feasible to measure by a paper-and-pencil test. As a result, it was agreed to assess skill groups 1, 3, 4 involving those particular skills in which development was self-directed by students (table 1, in bold). That means that when conducting activities students were expected to formulate hypotheses, design an experiment, analyse and interpret data and form arguments with minimal help from the teacher.

The test was designed in several steps. Firstly, a database of test items was developed based on the analysis of existing tests. Twenty-seven teachers involved in the research evaluated the test items considering their difficulty in relation to curriculum and age group. They also considered how the test item corresponds to the assessed skill. In both cases a 5-point scale in the range from -2 to +2 was used. Only the items with a positive average value were selected, discussed in detail and modified. In order to ensure the test content validity at least two test items were assigned for each skill group. This way the first version with 13 test items was designed and taken by students from three classes of three different high schools. On the basis of pilot testing this version was modified again. Respecting the limited time of one lesson for the test administration the test was reduced.

The final version of the test of selected inquiry skills (TSIS) involves 12 items related to the context of mathematics, physics and informatics. Test reliability determined via a Cronbach Alpha analysis is $C_\alpha = 0.68$, while using a split-half method its value reaches 0.7. Both values can be considered acceptable taking into account the limitation connected with a relatively small number of items, as suggested by many researchers (Cohen et al., 2007; Marx et al., 2004).

There are two slightly different versions that were implemented as pre-test and post-test. Even though the number of test items seems to be rather low, the test takes one lesson to administer. In addition to multiple-choice items with one or two correct answers out of five answer choices the test involves also two open-ended items. In two multiple-choice items aimed at argumentation skills the students are expected to add arguments to explain reasons for their choice of answer (table 3).

Table 3. Distribution of test items with regard to inquiry skills, subject and type of item.

Item	Inquiry skills	Subject	Type of item
1.1	Formulate hypothesis or expectation to be tested.	Physics	multiple-choice 2 correct answers
1.2	Design experiment (which variables, which relationship).	Physics	open-ended
2	Design experiment (which variables, which relationship).	Informatics	multiple-choice 1 correct answer
3	Discuss/ defend results/form arguments.	Mathematics	multiple-choice with argument
4	Determine relationships between variables based on data in text.	Mathematics	multiple-choice 2 correct answers
5	Design experiment (which variables, which relationship).	Physics	multiple-choice 2 correct answers
6	Determine relationships between variables based on graphs.	Mathematics/ Physics	multiple-choice 1 correct answer
7.1	Transform results into standard form (i.e. tables, graphs).	Informatics	open-ended

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Item	Inquiry skills	Subject	Type of item
7.2	Determine relationships between variables based on data in tables.	Informatics	multiple-choice 1 correct answer
8	Determine accuracy of experimental data (identify possible sources of errors).	Physics	multiple-choice 1 correct answer
9	Determine relationships between variables based on tables.	Informatics	multiple-choice 1 correct answer
10	Discuss/defend results/form arguments.	Mathematics	multiple-choice with argument

The students´ answers to the test items were evaluated on the basis of agreed criteria. They were assigned a value of 0-1 point which means that students could achieve a test score in the range of 0-12 points. For multiple-choice items with one correct answer students got 1 point for the correct choice, but in all other cases (even when the correct answer was combined with another option) they got 0 points. Multiple-choice items with two correct answers were scored with 1 point only in the case of choosing just two right answers and 0.5 points were assigned in the case of choosing just one answer that was right. In all other cases the score of 0 points was assigned. Multiple-choice items with arguments added to the choice of answer were scored with 0.5 points in the case of choosing just one right answer. Remaining 0.5 points were assigned on the basis of correct reasoning. Open-ended items were scored by 0-1 point according to the correctness and completeness of the answer.

Data Analysis

After collecting data from pre-test and post-test the qualitative and quantitative analysis was carried out. From the whole research sample only data of the students who took both pre-test and post-test were involved into analysis. Data of four students who did not respond to six or more test items were eliminated from the analysis.

The basic descriptive statistics was used to summarize the main features of the sample distribution and test results expressed in percentage. The following advanced data analysis (Rencher, 2003; Lynch, 2013) was divided into several parts in accordance with the addressed research questions.

For testing differences (total gain) in the matched overall pre- and post-test scores, the paired sample *t*-test was applied. Regarding the effect of the given factors (grade, gender, specialization) on the total gain, conditions of the two-way analysis of variance (ANOVA) were satisfied for gender and class specialization. Subsequently, for multiple comparisons, Tukey's method was used. The influence of grade was examined separately employing the Mann-Whitney test.

An improvement in three skill groups was determined by multivariate one-sample Hotelling T^2 test with χ^2correction. Finally, to preserve an exact error rate (*p*-value), we considered Bonferroni's adjustment in Wilcoxon's tests comparing performance in individual skill group before and after implementation of inquiry activities. Considering performance in skill group 3, three-way ANOVA was applicable to find out significance of specialization, gender and grade.

In all mentioned parts of the data analysis normality of differences or residuals was being confirmed by the Shapiro-Wilk test. The statistical analysis was realized in R and SPSS software (Nordhausen, Sirkia, Oja & Tyler, 2012; IBM Corp, 2015; R Core Team, 2016).

Results of Research

The table 4 represents a numerical summarization for a studied sample consisting of 300 students who performed both pre-test and post-test.

Table 4. Distribution of the research sample reflecting grade, gender and class specialization.

Factor	Grade		Gender		Specialization		
	1	2	F	M	General	Languages	Math/Inf
Distribution	140	160	158	142	149	75	76
%	46.7	53.3	52.7	47.3	49.7	25	25.3

The basic descriptive statistics concerned pre-test and post-test results is reported in table 5.

Table 5. Results of pre-test and post-test.

		Pre-test (%)				Post-test (%)			
		Mean	Median	Std. Dev.	SE	Mean	Median	Std. Dev.	SE
	Sample	34.5	33.3	17.7	1.0	41.5	39.4	18.1	1.0
Grade	First	33.5	30.8	17.5	1.5	40.9	39.4	18.5	1.6
	Second	35.4	34.0	17.8	1.4	42.0	39.4	17.8	1.4
Gender	Male	39.2	37.5	18.8	1.6	47.1	47.3	19.3	1.6
	Female	30.4	31.3	15.5	1.2	36.5	35.4	15.5	1.2
Specialization	General	32.3	31.3	15.5	1.3	37.5	35.4	15.0	1.2
	Language	30.8	29.6	18.3	2.1	36.4	35.4	18.8	2.2
	Math/Inf	42.6	41.9	18.8	2.2	54.4	55.0	17.1	2.0

Std. Dev. – standard deviation, SE – standard error of the mean

From the table 5 it can be seen that the initial level of selected inquiry skills reached the mean score of 34.5% for the whole sample. This result is lower than expected, although the test was considered appropriate and not difficult according to teachers who assessed individual test items.

Even the 2nd grade students, who had already spent one year at the high school during which their inquiry skills should have been improved, did not achieve the average score of 40% and moreover, the difference between pre-test score for the 1st and 2nd grade students was not significant ($p = 0.342$). This score of 40% was almost reached by boys (39.2%) and was overcome by the students from math/inf classes (42.6%) who are selected to these classes on the basis of their positive attitude towards math or informatics and good achievements in these subjects.

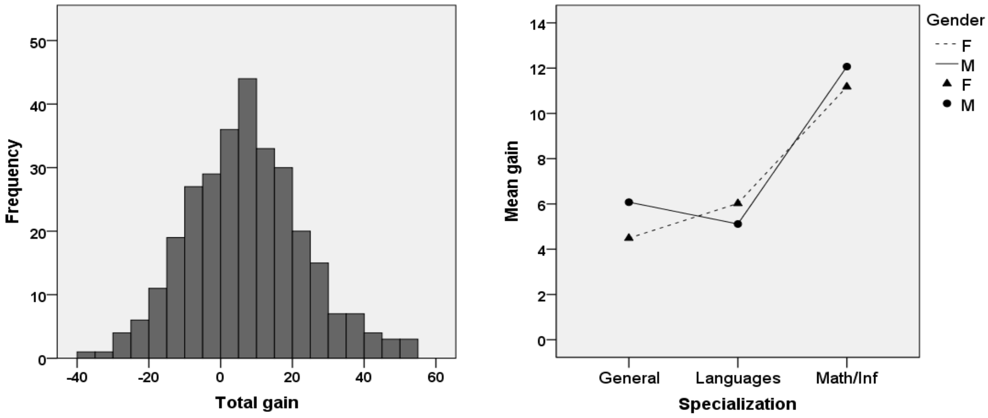

Figure 2: Distribution of students´ total gains (total gain=%post-%pre, left) and comparison of mean gains across different groups (right).

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Based on the statistical testing of hypothesis H_{01}, the paired sample *t*-test ($t(299)=7.43$; $p < 0.0005$) showed a statistically significant difference in overall test score after a period of consistent implementation of inquiry activities (table 5). For the whole sample the mean score has shifted from 34.5% to 41.5% breaking the level of 40% (median shifting from 33.3% to 39.4%). The mean gain reached the value of 7% (table 5, figure 2 - left).

Considering the question about factors influencing the students' gain (hypothesis H_{02}), there were several tests conducted. As for the effect of gender and class specialization a two-way ANOVA proved that class specialization is statistically significant factor affecting the total gain ($F(2, 294) = 4.014$; $p = 0.019$), while gender is not ($F(1, 294) = 0.068$; $p = 0.795$). Also, gender and class specialization do not interact significantly ($F(2, 294) = 0.144$; $p = 0.866$), what can be seen from the similar graph profiles for females and males (figure 2 – right). No interaction means that the effect of specialization on students' gain does not depend upon gender, or in other words the specialization increases the gain for boys in the same way as for girls.

The following multiple comparisons table (table 6) summarizes Tukey's post-hoc tests. Tukey's method revealed that there was a statistically significant difference between general classes and classes specialized in math/informatics ($p = 0.012$), and boundary difference between languages and math/inf classes ($p = 0.056$). These results indicate that in math/inf classes the experimental instruction had the largest effect on students.

Table 6. Multiple comparisons between different groups.

Multiple Comparisons (Dependent Variable: total gain)					
(I) Specialization	(J) Specialization	Mean Difference (I-J)	Sig.	95% Confidence Interval	
				Lower Bound	Upper Bound
General	Languages	-0.5	0.975	-5.9	4.9
General	Math/inf	-6.6	0.012	-11.9	-1.2
Languages	Math/inf	-6.1	0.056	-12.2	0.1

As for the effect of grade, the Mann-Whitney test showed no statistically significant difference ($p = 0.348$) between groups determined by this factor. This means that the experimental instruction affected the 1st and 2nd grade students in the same way.

Finally we considered improvement in three inquiry skill groups (1, 3, 4) described in the following table 7 and graphs in figure 3.

Table 7. Results of pre-test and post-tests grouped by skills 1, 3, 4.

		Pre-test (%)				Post-test (%)			
Skills	Items	Mean	Median	Std. Dev.	SE	Mean	Median	Std. Dev.	SE
1	1.1, 1.2, 2, 5	40.5	37.5	22.5	1.3	46.7	43.8	21.6	1.2
3	4, 6, 7.1, 7.2, 8, 9	35.0	33,3	21.9	1.3	40.1	41.7	22.8	1.3
4	3, 10	21.3	25.0	21.8	1.3	35.3	25.0	27.2	1.6

The multivariate analysis based on one-sample Hotelling T^2 test with χ^2 correction ($T^2 = 102.06$; $df = 3$; $p < 0.0005$) confirmed the mentioned improvement in three selected inquiry skill groups together. In addition, Wilcoxon's tests also revealed an improvement in every considered inquiry skill (Bonferroni adjusted $p < 0.0015$).

Having a closer look at the effect of different factors on the gain in the area of skill groups 1, 3, 4, some interesting facts emerge from figure 3 (right). Data presented here indicate that in skill group 1 the mean gain of different classes is similar, nevertheless, there can be a slightly higher gain identified for language classes' students. This concerns test items about formulating question and corresponding hypothesis and identifying variables in experimental design. It seems that in this kind of items math/inf classes´ students do not have an extra advantage to be ahead of other groups. On the other hand, the highest mean gain in skill group 4 aimed at argumentation skills was obviously achieved by math/inf classes' students, with the language classes' students lagging significantly behind the other classes. This is not so surprising since the test items were situated in mathematical context that might play a significant role in favour of math/inf classes.

Focusing on skill group 3, three-way ANOVA confirmed that only specialization is a significant factor ($F(2, 288) = 5.081$; $p = 0.007$), while gender ($F(1, 288) = 0.096$; $p = 0.757$), grade ($F(1, 288) = 0.211$; $p = 0.647$) and all mutual interactions are insignificant. The following multiple comparisons analysis analogical to table 6 showed a statistically significant difference between math/inf and general classes ($p = 0.001$) and also math/inf and languages classes ($p = 0.014$). This means that in skill group 3 the largest gain was achieved by math/inf classes. The reason apparently lies in higher level of mathematical literacy of math/inf students that might cause larger effect on the development of interpretation and analysis skills compared to the language or general classes.

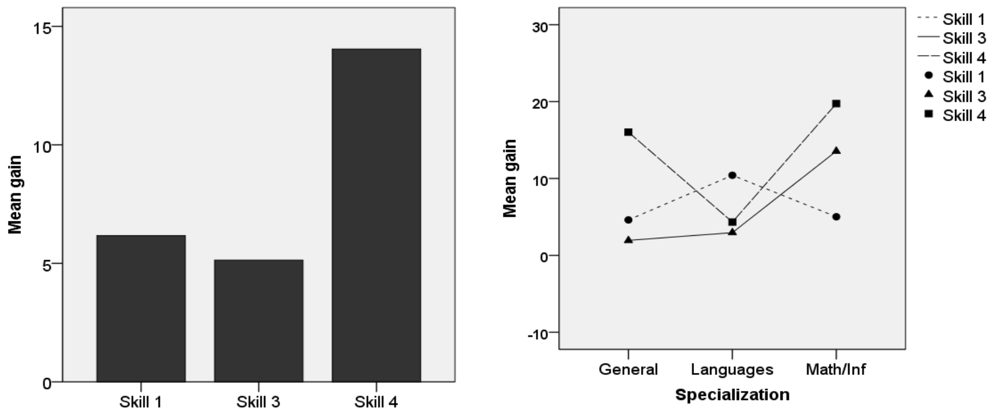

Figure 3: Comparison of mean gains across the skills 1, 3, 4 (left) with regard to different groups (right).

Discussion

The results show that the designed model of coactive IBSE implementation in mathematics, physics and informatics is efficacious in terms of development of students´ selected inquiry skills.

More detailed analysis of research findings revealed several interesting results. The initial level of selected inquiry skills is rather low (mean score of 34.5%). This is not so surprising, taking into account the results of international PISA assessment, for Slovak 15 year old students, in particular. While in PISA 2012 with focus on testing mathematical literacy Eastern European countries involving Slovakia in the subscale of employing mathematical concepts and facts belongs to the best OECD countries, on the other hand, in the subscale of interpreting, applying and evaluating mathematical outcomes Slovakia is near the bottom of the list of OECD countries (OECD, 2014). Also, in the field of scientific literacy that was in main focus of PISA 2006, the knowledge of science was much stronger while students tend to do less well in questions relating to the understanding of the nature of scientific work and scientific thinking. Slovak students did not achieve the sufficient level corresponding to the skills to interpret a dataset expressed in a number of formats, such as tabular, graphic and diagrammatic, by summarizing the data and explaining relevant patterns (Bybee & McCrae, 2009). As reported in PISA 2012 (OECD, 2014), science performance remained broadly stable since 2006.

Having a closer look at the students of different grades, surprisingly, there was no statistically significant difference identified between pre-test results of 1st and 2nd grade students. This fact indicates, that 2nd grade students probably did not experience IBSE during their first year of study and hence were not ahead of their novice schoolmates from the 1st grade. This suggests that the more traditional instruction without consistent implementation of IBSE does not bring substantial effect on learning gains in the field of inquiry skills, however, the scientific knowledge might achieve a sufficient level. It is generally agreed that even good level of scientific knowledge understanding achieved during the instruction cannot guarantee the corresponding level of inquiry skills (OECD, 2007, 2014). Marx et al. (2004) identified even stronger effect of IBSE on content understanding compared to process skills. These results imply that while implementing IBSE, the development of inquiry skills cannot be taken for granted and for achieving significant results a consistent and intentional IBSE implementa-

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tion targeted on inquiry skills development is needed. However, most existing studies investigated the effect while implementing IBSE in a single science subject of either biology, ecology, chemistry, physics or integrated science (Minner, Levy & Century, 2010; Gormally et al., 2009; Wilson, et al., 2010; Marx, et al., 2004; Pešaković, et al., 2014; Beck & Blummer, 2012). In this research, the multidisciplinary approach to IBSE was designed and inquiry activities were implemented coherently and intentionally across the three subjects proving the efficacy of coactive implementation.

As for the different factors influencing the learning gains, the largest effect has been identified for the math/inf classes where students are selected on the basis of their interest towards mathematics and informatics and the level of knowledge in these subjects. That is in line with research results showing that the learning gains are impacted by inner motivation (Škoda, et al., 2015). Besides, based on students' comments, language classes´ students are more in favour of traditional deductive approach based on teacher-directed lecturing and explaining the learning content. In more student-centered activities they feel uncomfortable and they are not sure about what is important to know and understand for the test. This result supports the opinion of Rocard et al. (2007) who emphasize that these two approaches should be combined to accommodate for different mindsets and age groups preferences.

Neither gender nor grade plays a role concerning learning gains. Considering gender, the fact that the impact is not gender-biased (for the whole sample and also for the classes of different specialization) can be considered a positive attribute of the designed model of IBSE. Other researchers report that gender differences in students´ achievements have decreased over the past few decades (Francis & Skelton, 2011; Hyde & Linn, 2006). This is also declared by PISA assessments showing no gender differences in the science achievements for most countries (OECD, 2007, 2014).

As for the individual skill groups analysed in the research, the statistical testing also confirmed improvement in every considered group of inquiry skills. Considering the skill group 4 (Communication with focus on argumentation skills), other studies have also proved the positive impact of IBSE in the field of development and construction of evidence-based arguments (Wilson et al., 2010; Ruiz-Primo, Li, Tsai & Schneider, 2010). Nevertheless, these authors comment that many answers requiring reasoning and forming arguments to draw conclusions were incomplete or fragmented. That is in line with this research identifying a lot of answers with missing arguments despite the positive effect of IBSE in this specific area of inquiry skill group. Considering skill group 1 (Formulating question and corresponding hypothesis and identifying variables in experimental design) and 3 (Analysis and interpretation) the positive effect was achieved. Similar results have been identified by Roth and Roychoudhury (1993) after implementing inquiry lab sessions in three different grades during the physics or general science lessons. Findings from their study indicate that students learned to identify and define pertinent variables, interpret, transform and analyse data, plan and design an experiment and formulate hypothesis. The authors suggest that process skills need not be taught separately but in a meaningful context. Following this principle, within this research inquiry activities were implemented in not only meaningful context of physics but also in the context of mathematics and informatics (see examples in table 2). The fact that in skill group 3 the largest effect was identified for math/inf classes corresponds to their higher level of mathematical literacy, while this advantage apparently does not play a role in the skill group 1 where all classes achieved similar gains.

Considering skill group 3, deeper qualitative analysis of the individual test items revealed some interesting facts regarding students´ difficulties and misconceptions. In transforming data gained from sound recordings of different parameters (time length, file size and number of channels) into the corresponding graph (item 7.1), students have still difficulties to identify the independent and dependent variable in order to design the appropriate relationship and its corresponding graph (pre-27.4%, post-33.7%). Also, when determining the relationship between variables based on a table (item 7.2) the common students´ misconception is the confusion between linear relationship and direct proportionality (pre-32.7%, post-39.3%). Determining the relationship between variables based on a distance vs. time graph of two runners (item 6), the majority of students are able to read basic information from the graph (e.g. that the interconnection of two graphs corresponds to the situation that one runner reaches the other), however, the question about who reaches whom is answered wrong by many students. They assign higher average speed to the runner whose distance vs. time graph lies higher than that of the other during most of the time (pre-33%, post-38.7%). This corresponds to the common students´ misconception connected with variable confusion (Beichner, 1994), i.e. in this case students mix the distance with speed not realizing that the higher average speed corresponds to the runner whose speed is higher than that of the other during most of the time.

Even though there was an overall positive shift for skill group 3, in item 8 students achieved negative gain (pre-29.7%, post-18.7%). This item was aimed at determination the accuracy of experimental data gained while measuring position of a moving sailboat (with the corresponding post-test item about weights of a number of masses). Just a small number of students is able to identify the most likely reason for the slight scatter in the graph data. This result suggests that although the inquiry activities implemented in physics lessons involved discussion about possible errors and their sources, this discussion is usually set at the end of the activity and teachers may omit it due to lack of time and hence students have limited experience in this field. On the other hand, this result is not such a surprise, since even students of introductory university course have similar difficulties in understanding uncertainty in physics measurements (Abbott, 2003).

Conclusions

The presented research reports on the model of consistent implementation of inquiry activities across the three subjects of mathematics, physics and informatics and its efficacy with regard to the development of students' selected inquiry skills. The research findings based on the inquiry skills´ assessment before and after experimental teaching clearly indicate that the designed model of coactive IBSE implementation is efficacious for the selected inquiry skills development. More detailed analysis revealed that the learning gains differ for different groups of students based on class specialization, however it is gender and grade independent. The statistical testing also confirmed improvement in every considered individual group of inquiry skills. The highest gain in inquiry skills development as a whole is achieved by math/inf classes´ students. Math/inf classes achieved the highest gain also in the skill group of data analysis and interpretation and also communication with focus on argumentation skills. These results confirm the importance of mathematical literacy in the field of data analysis and evidence-based argumentation.

Even though there is an impact on the level of selected inquiry skills achieved, there is still some potential for improvement seen. There are many factors that influence the results, however, taking into account the fact that IBSE teaching and learning materials are within easy reach of teachers, the following factors are considered to be the most crucial:

1. Stronger teachers´ belief and confidence in IBSE is needed that could lead to more intensive effort while implementing inquiry activities.
2. Even more consistent multidisciplinary approach to IBSE across mathematics, informatics, physics, biology and chemistry or even other subjects is needed, so that students accept this approach as a natural way of education.

A limitation of this research is related to the sampling of classes that were not selected by random choice but on the basis of schools with long term cooperation where teachers are motivated to learn about new trends in education. Therefore, the results are applicable among classes/teachers with similar background.

Regarding the evident positive effect of coactive implementation of IBSE, it is recommended to apply the designed model of IBSE implementation in the school practice and integrate it into the school curriculum. Moreover, the use of the developed assessment instrument can facilitate teachers to monitor the learning gains in order to get feedback about the progress of inquiry skills development and decide about the further instructional intervention.

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