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INQUIRY-BASED SCIENCE EDUCATION AS A REVISION STRATEGY

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Abstract: *The research aim was to identify the effect of revising the thematic unit "Changes in Chemical Reactions" using IBSE (based on confirmation inquiry) in the 8th grade of secondary school. This thematic unit is taught in chemistry lessons in the 2nd term of the 7th grade. A set of activities verified by a piece of pilot research was used to implement IBSE based on confirmation inquiry using the 5E Educational Model. The research was performed in ten Slovak secondary schools during the 1st term of the 2017/2018 school year. This research employed the quasi-experimental methodology involving pre-test–post-test two-group design. The research sample consisted of 292 8th grade students. They were divided randomly into a control (n=149) and experimental (n=143) group, and the intervention took place during 10 lessons. Cognitive tests based on the revised Bloom's taxonomy were used to measure students' knowledge and skills before and after revision. The results indicate that using IBSE (based on confirmation inquiry) in the revision phase is more effective than teaching without using IBSE in terms of developing conceptual understanding. It affects the lower and higher cognitive processes (understanding, application, and analysis) and stimulates learning mainly in students with lower academic performance.*

Keywords: *chemistry education, cognitive processes, confirmation inquiry, secondary school.*

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Introduction

In the recent decades, it is recommended to use active inquiry methods in teaching and learning science. Inquiry, investigation, application of knowledge in new situations and on new problems and solutions are the best methods for students to develop their cognitive processes and performance skills (Pellegrino & Hilton, 2012).

An effective strategy is to implement Inquiry-Based Science Education (IBSE) in teaching as well as learning (Anderson, 2007; Brickman et al., 2009; Bruder & Prescott, 2013; Furtak et al., 2012; Harlen 2013; Krajcik et al., 2001; Minner et al., 2010; Rocard et al., 2007; Sadeh & Zion, 2009; Schroeder et al., 2007; Wilcox et al., 2015).

According to multiple researchers, IBSE is based on the constructivist approach (Eisenkraft, 2003; Llewellyn, 2002; White & Frederiksen, 1998). One of the models emphasizing the constructivist principles is the 5E Educational Model consisting of 5 phases: Engage, Explore, Explain, Elaborate, and Evaluate (Bybee et al., 2006).

From the students' viewpoint, inquiry is an active approach to learning that includes investigation of the surrounding world, which prompts the formulation of questions, discovering, and testing the findings to achieve deeper understanding. During the process, students collect and record information which they subsequently present in different ways; they also work with other information sources (books, videos, Internet), and communicate with others (peers, teacher, experts, etc.). Drawing meaningful conclusions requires reflection, discussion, comparison of findings with others, interpreting obtained information, and application of new knowledge in different contexts (Ash & Kluger-Bell, 2000). In IBSE, the teacher changes from an authority/leader to a guide (Windschitl, 2002).

Researchers have specified several different levels of inquiry based on the amount of information provided to the students (e.g. helping questions, instruction on the investigation procedure, instruction for data processing, etc.) or how much the teacher governs the activity and helps the students (e.g. asking questions, commenting, instructing, etc.) (Banchi & Bell 2008; Bell

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et al., 2005; Buck et al., 2008; Fradd et al., 2001; Rezba et al., 1999; Walker, 2007). For example, the 5-level inquiry model (Table 1) designed in the ESTABLISH project (European Science and Technology in Action: Building Links with Industry, Schools and Home).

Table 1
Inquiry levels as proposed in the ESTABLISH project (ESTABLISH, 2010)

Inquiry level	Question (problem)?	Methods (solutions)?	Result (conclusion)?		
Interactive discussion/demonstration The teacher asks questions in an interactive way and leads student discussion or asks questions and requires students to answer, explain and provide evidence obtained by experimenting.	x	x	x	high	teacher
Guided discovery (confirmation inquiry) Students confirm (verify) a law (knowledge, connections) through an activity whose result they already know.	x	x	x	← supporting learning materials →	← activity led by →
Guided inquiry Students solve a problem formulated by the teacher using a procedure prepared in advance, but they do now know the result.	x	x			
Bounded inquiry Students solve a problem formulated by the teacher using a procedure they prepare (design) on their own.	x				
Open inquiry Students solve a problem they formulate on their own based on a procedure they prepare (design) on their own.				low	student

The research of IBSE implementation in teaching and learning has proven the effect of IBSE in developing conceptual understanding (Kirschner et al., 2006; Laksana et al., 2019; Marshall & Horton, 2011; Minner et al., 2010; Schroeder et al., 2007), problem-solving abilities in students (Prince & Felder, 2007), developing critical thinking (Aksela, 2010; Baker et al., 2008), developing cognitive and scientific skills (Barron & Darling-Hammond, 2008; Brickman et al., 2009; Kirschner et al., 2006; Lederman et al., 2014; McLoughlin et al., 2012), promoting motivation and interest (Rocard et al., 2007; Škoda et al., 2015; Wang et al., 2015), and developing positive attitudes to science (Hattie, 2009; Llewellyn, 2013). IBSE allows for better understanding of the scientific procedures and develops scientific literacy (Bass et al., 2009; Goodrum & Rennie, 2007; Harlen, 2004; Marshall & Alston, 2014; Marshall et al., 2016; Minner et al., 2010). It is suitable for all types of students: low as well as high performing ones (including the gifted students), boys and girls, all age groups (Trna et al., 2012).

However, there are also studies that have shown no significant influence of IBSE on students' learning process or their learning outcomes (Chang & Mao, 1999; Schneider et al., 2002; Von Secker & Lissitz, 1999) no improvement in terms of understanding natural phenomena (Khisfe & AbdEl-Khalick, 2002) or enhanced understanding of scientific procedures (Berg et al., 2003; Klahr & Nigam, 2004).

The ambiguous results of research comparing IBSE with other teaching methods may result from the fact that often, teaching methods used in the control groups have not been clearly defined, merely referred to as "traditional teaching methods" with no further specification, or there has been no control group at all.

Research Problem

The main aim of science education in Slovakia is to develop science literacy and capabilities necessary for future scientific work (ŠPÚ, 2014). The individual cycles of the OECD PISA international comparative assessment (Programme for International Student Assessment) have been pointing out since 2003 that Slovak students' performance in scientific literacy are below the OECD average (OECD, 2019). Slovak students understand and remember what they are taught in science lessons, however they fall behind their peers in other OECD countries in terms of higher-order cognitive processes such as application, analysis, assessment, and creativity. They have difficulties

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with independent reflecting on science phenomena and connections, assessing and formulating hypotheses, searching for and proposing solutions, interpreting the obtained data, drawing conclusions, and supporting their arguments with evidence (Miklovičová et al., 2017). Slovak students are acquiring knowledge and skills on the lower cognitive process level when the traditional lecture-based model is used. Can their knowledge and skills be enhanced through IBSE-based revision? In many studies, IBSE strategies have been implemented into teaching and learning to present the learning content in an accessible way (acquisition of knowledge and skills) on the given level of education (ISCED) in the respective year as provided in the educational standards. Many teachers believe that revision can be performed using different conditions and situations to enhance students' knowledge and skills (Kang, 2016; Montessori, 2017; Petlák, 2004).

Research Aim and Research Questions

The aim of the presented research was to identify the effect of revising the thematic unit "Changes in Chemical Reactions" using IBSE (based on confirmation inquiry) in the 8th grade of secondary school. The learning outcomes in the revision with the implementation of IBSE were compared with the learning outcomes of teaching without using IBSE. Cognitive tests with items in different domains of the revised Bloom's taxonomy were used to measure the learning outcomes (knowledge and skills) – a pre-test was given before the revision and a post-test was given afterwards. The tests' results were compared, and the obtained data were processed to evaluate the effect of teaching methods.

The research questions were defined as follows:

1. How much does revision using IBSE (confirmation inquiry) affect students' conceptual understanding?
2. Which students, in terms of academic performance, benefit from revision using IBSE?

Research Hypotheses

The research hypotheses verified within the research reflect the above-mentioned main research aim. The following hypotheses were formulated and tested:

H_{01}: Before the revision, the knowledge and skills of the experimental group and the control group are the same.

H_{02}: After the revision, the knowledge and skills of the experimental group and the control group are the same.

H_{03}: After the revision, the knowledge and skills of the experimental group and the control group in the cognitive process categories (remember, understand, apply, and analyse) are the same.

H_{04}: Before and after the revision, the knowledge and skills of the experimental group in terms of academic performance are the same.

Research Methodology

General Background

Pre-test and post-test two-group design was employed in the research (Cook & Campell, 1979). Within a specified period of time, an experimental intervention was performed within the experimental group while the control group remained unaffected. The teaching method as an independent variable was manipulated to identify its effect on the dependent variable (in this case, knowledge and skills). Both groups were tested using the same methods before and after the experiment.

The research was performed in the first term of the 2017/2018 school year – from September to mid-October. The research was conducted at ten secondary schools in five regions of Slovakia (Prešov, Košice, Trenčín, Trnava, and Žilina regions). The selection of schools and teachers was deliberate. All 11 teachers (all women with more than 10 years of experience) who participated in the research took the "Innovative Methods in Teaching Chemistry and the Development of Key Competences in Students" course at Pavol Jozef Šafárik University in Slovakia. The course consisted of 8 contact lectures and 2 e-learning distance lessons. The course included lectures during which the teachers learned about the IBSE theory and inquiry activities pertaining to general, inorganic, and organic chem-

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istry topics. Subsequently, the teachers performed selected inquiry activities themselves. In the distance lessons, the teachers designed inquiry activities for a selected topic.

Ethical Considerations

The participation of teachers and students in the research was voluntary. The participants were given an Information Sheet and a Consent Form in advance. Before the research began, they were informed about their role in the research, time schedule, and data publishing. Information about students was obtained from the teachers based on the written consent of their parents (legal guardians). For the purpose of statistical processing and evaluation of the data collected, all teachers and students were assigned identification codes to maintain their anonymity.

Sample

The research sample consisted of 292 8th grade students. 135 (46.2%) participants were male and 157 (53.8%) female. The students were aged 13–14. The experimental group consisted of 143 (49%) students and the control group consisted of 149 (51%) students. Table 2 summarizes the number and percentage of students based on genders and academic performance in chemistry at the end of the 7th grade (1=great performance to 5=fail).

Table 2
Characteristics of the experimental and control group

Variable		Experimental group *n*=143		Control group *n*=149	
		Number of students	Percentage	Number of students	Percentage
Gender	Male	63	44	72	48
	Female	80	56	77	52
Total		143	100	149	100
Academic performance in chemistry at the end of the 7th grade	Students with grade 1	69	48.3	89	59.7
	Students with grade 2	39	27.3	38	25.5
	Students with grade 3	31	21.7	15	10.1
	Students with grade 4	4	2.7	7	4.7
Total		143	100	149	100

Content Area

In Slovakia, secondary school students start learning chemistry as a separate subject in the 7th grade (ISCED 2). The "Changes in Chemical Reactions" thematic unit is taught in the second term of the 7th grade. The formal SA standard for "Changes in chemical reactions" covers (ŠPÚ, 2014):

- *Content standards*: thermal changes during chemical reactions (exothermic and endothermic reactions), rate of chemical reactions, examples of slow and quick reactions, factors affecting the rate of chemical reactions.
- *Performance standards*: provide real life examples of exothermic and endothermic reactions, perform experiments to measure thermal changes during chemical reactions, record the results in tables and interpret them, distinguish slow and quick reactions, perform and evaluate experiments investigating how different factors influence the rate of a chemical reaction.

In the 7th and 8th grades, there are two chemistry lessons per week/66 lessons per term. In the 8th grade, 10 lessons are designated to revise the learning content from the 7th grade. The curricula for teaching in the 7th grade and revising in the 8th grade are identical.

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Confirmation Inquiry Activities

For the purpose of the "Changes in chemical reactions" thematic unit, a set of five inquiry activities was created within the National project "IT Academy – Education for the 21st Century". The activities were created according to the 5E Educational Model and focused on confirmation inquiry (second level of inquiry according to the hierarchy designed in the Establish project). Two lessons were designated for each inquiry activity. The inquiry activities are described in Appendix A.

The activities created were verified during a pilot research performed in the second term of the 2016/2017 school year; the sample consisted of 450 students taught by 25 teachers. The design-based research (DBR) methodology was used in this research. Based on the research results, the activities were optimised (Sotáková et al., 2020).

Characteristics of Confirmation Inquiry Activities

In confirmation inquiry activities students worked in pairs or groups of 3–4. First, students learned about the problem from a worksheet (based on the 5E Model): e.g. how crushing of a sodium bicarbonate tablet affects its reaction with vinegar. Students' task was to formulate their assumptions about the expected outcome. Subsequently, students verified their assumptions in practice, formulated their explanations (based on the experiment) and recorded them in the worksheets. In the phase of knowledge and skill enhancement, students applied them in new, real-life situations (e.g. correct fire setting methods, proper chewing of food, limescale removal). In course of the lesson, the teacher guided the students by asking suitable questions.

As an example, "The Effect of Temperature on the Rate of Chemical Reactions" inquiry activity was selected for demonstration (Table 3). The aim of this activity was to perform and evaluate an experiment to verify how temperature affects the rate of chemical reaction between vinegar and sodium bicarbonate.

Table 3
"The Effect of Temperature on the Rate of Chemical Reactions" inquiry activity

Engage
In this phase, the teacher tries to engage the students and motivate them to investigate the presented phenomenon. They ask questions such as: 1. What are the properties of vinegar and what is it used for? 2. What are the properties of sodium bicarbonate and what is it used for? 3. Do you know how vinegar and sodium bicarbonate react? 4. *Which factors could affect how vinegar and sodium bicarbonate react?* In this phase, the teacher can examine students' knowledge and ideas to collect, record, and identify possible misconceptions.
Explore
The teacher divides students into pairs or groups of 3–4 and hands them worksheets. Task 1: Try to estimate how the temperature of vinegar can influence the course of its reaction with sodium bicarbonate. Write down your assumptions. Subsequently, students verify the effect of temperature on the course of this chemical reaction. Task 2: Perform the experiment according to instructions. Since students will perform the experiment on their own according to the instructions, it is necessary to warn them about the safe use of chemicals and laboratory instruments. The teacher prepares the instruments and chemicals in advance according to the number of student pairs or groups. Instruments: 3 identical volumetric flasks (100 ml), 2 graduated cylinders (50 ml), 2 beakers (400 ml), 3 identically sized balloons, funnel, spatula, filtration paper, scales Chemicals: vinegar, sodium bicarbonate, water Students perform the experiment to observe the reaction of vinegar and sodium bicarbonate using simple apparatus (flask with a balloon on its neck) at different temperatures (one 400 ml beaker is half-filled with cold water and the other with warm water). The ambient temperature will be used for comparison. Note: Flasks with vinegar need to be dipped in cold and warm water respectively before the reaction – so that the difference between the rate of chemical reactions is visible.

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Explain

In this phase, the teacher aims to confront students' results with their knowledge and possible misconceptions identified in the previous phase.

Task 3: Answer the following questions.

1. *Write down what you observed 10 seconds after pouring sodium bicarbonate into vinegar.*
2. *In Figure 1, mark the course of the reaction in the banks dipped in cold and warm water respectively to clearly show, which reaction was quicker.*
3. *Correct the statements (cross out what is incorrect).*
   In the flask dipped in cold water more/fewer bubbles were produced and the rate of reaction was higher/lower.
   In the flask dipped in warm water more/fewer bubbles were produced and the rate of reaction was higher/lower.
4. *Write down which balloon was blown up more quickly.*
5. *Write down the name of the gas that blew up the balloons.*
6. *Did crushing the sodium bicarbonate tablet the reaction rate?*
7. *Write whether the higher temperature of the vinegar increased or decreased the rate of this reaction.*

Task 4: Discuss in your group and explain how the change of temperature affects the rate of chemical reactions.

Figure 1
The effect of temperature on the reaction rate between vinegar and sodium bicarbonate

Elaborate

Task 5A: Provide examples of other substances whose reaction with vinegar you would like to see. (Examples: reaction of vinegar with egg shells, chalk or mussel).

Task 5B: Discuss in your group, then answer the following questions.

1. *Why do we keep food in a fridge or freezer?*
2. *Why does food cook sooner in a pressure cooker than in a normal pan?*

Evaluate

This phase focuses on formulating questions developing higher-order cognitive processes, thus helping students develop their skills, judge, evaluate, analyse, and interpret the results of their work.

Task 6: Students evaluate their own knowledge and skills by filling in the table focused on meta-cognition. In Table 3 they record the knowledge and skills learned on the occasion, in Table 2 they record the information they consider the most interesting, and in Table 1 they write a question whose answer they still do not know.

Instrument

Tests

Standardised cognitive tests were used as the research instrument for the pre-test and post-test (Rabčan et al., 2019). Both the pre-test and the post-test consisted of 10 items focusing on different domains of the revised Bloom's taxonomy (Anderson & Krathwohl, 2001). The tests were comparable, they included the learning content of the "Changes in chemical reactions" thematic unit according to the content and performance standards defined in the formal SA standard (ŠPÚ, 2014). The items focused on the following categories of a) knowledge dimension: factual (1 item), conceptual (8 items) and procedural (1 item), and b) cognitive process dimension: remember (1 item), understand (4 items), apply (4 items), and analyse (1 item) (see Table 4). As for the task type, 5 items were single-choice questions and 5 were open questions with short answer. These items were developed and standardized by the National Institute for Certified Educational Measurements of Ministry of Education, Science, Research and Sport of Slovak Republic. Unfortunately, the database did not contain items pertaining to the "evaluate" and "create" domains.

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Table 4
Pre-test and post-test items based on the revised Bloom's taxonomy

Item number	Category: knowledge dimension	Category: cognitive process dimension
1	Conceptual	Remembering
2	Conceptual	Understanding
3	Conceptual	Understanding
4	Conceptual	Understanding
5	Procedural	Understanding
6	Factual	Application
7	Conceptual	Application
8	Conceptual	Application
9	Conceptual	Application
10	Conceptual	Analysis

Procedures

Before the beginning of the research the teachers took a 20-question self-assessment survey (Holloway, 2015). The questionnaire consisted of questions assessing their use of IBSE in chemistry by means of five subscales focused on the 5E educational model (Engage, Explore, Explanation, Elaborate, Evaluate). Questions were rated on a 5-point Likert-type scale: 1=almost never, 2=rarely, 3= sometimes, 4=often, 5=very often. A high overall score indicated that IBSE was used frequently, while a low score indicated that the traditional lecture-based approach prevailed. All teachers achieved medium scores as they reported using the IBSE (5E Educational Model) at least 70% of the teaching time. The teachers for the research were selected deliberately to ensure comparable IBSE skills.

At the beginning of September 2018, all students took the pre-test. Its goal was to identify and compare their level of knowledge and skills in the "Changes in chemical reactions" thematic unit taught during the previous school year in the period from February to June 2018. The pre-test results showed that all classroom groups were at a statistically similar level ($p>.05$). Therefore, the classroom groups were subsequently randomly assigned to either the control ($n=8$) or experimental ($n=7$) group.

After the pre-test, both groups proceeded to revise the "Changes in chemical reactions" thematic unit in the course of 10 lessons from September to mid-October 2018. In the experimental group, revision was performed using IBSE (confirmation inquiry) and in the control group IBSE was not used at all. In the experimental group revision was carried out using the five inquiry activities. Students worked in pairs or groups of 3-4; students with different academic performance were mixed. In the control group, teachers revised the topic using methods of their choice, e.g. questions & answers, oral and written revision, textbook studying, demonstration experiments, laboratory work.

After 10 lessons focused on revising the "Changes in chemical reactions" thematic unit, all students were administered the post-test.

Data Analysis

Students' pre- and post-tests were evaluated. 1 point was awarded for each correct answer; 0 points were awarded for an incorrect answer; the maximum score was 10 points. Data were processed using Excel and analysed. The overall test score was analysed as well as specific scores for different cognitive process categories and individual items. The reliability of the tests results was calculated using the Cronbach's alpha (Cronbach, 1951) and equalled for the pre-test ($\alpha=.693$) and for the post-test ($\alpha=.702$). Also, normal distribution of the results was controlled for total scores, grouped items, and for each item separately, using the Kolmogorov-Smirnov test. The Kolmogorov-Smirnov test confirmed that the obtained data showed non-normal distribution ($p<.001$), therefore the non-parametric Mann-Whitney *U* test was used to compare the data of the control and experimental groups.

Statistical analyses were performed using SPSS version 18 (SPSS Inc., 2009). In all data analyses, the *p* value <.05 was considered significant.

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Research Results

The Mann-Whitney *U* test results for the pre-test and post-test can be seen in Tables 5 and 6.

Table 5
The Mann-Whitney U test results in pre-test

Item		Experimental group			Control group			*p*
		$\bar{x}$	*MD*	*SD*	$\bar{x}$	*MD*	*SD*	
Items separated	Item 1	.66	1.00	.472	.69	1.00	.477	.344
	Item 2	.37	.00	.483	.39	.00	.487	.393
	Item 3	.18	.00	.386	.19	.00	.389	.464
	Item 4	.29	.00	.452	.32	.00	.466	.301
	Item 5	.90	1.00	.306	.90	1.00	.310	.476
	Item 6	.87	1.00	.339	.85	1.00	.335	.374
	Item 7	.46	.00	.499	.45	.00	.497	.433
	Item 8	.37	.00	.483	.35	.00	.488	.413
	Item 9	.67	1.00	.470	.66	1.00	.468	.500
	Item 10	.38	.00	.485	.40	.00	.490	.356
Items grouped	Remembering	.66	1.00	.472	.69	1.00	.477	.344
	Understanding	.59	1.00	.491	.58	1.00	.495	.448
	Application	.43	.00	.496	.45	.00	.498	.404
	Analysis	.38	.00	.485	.40	.00	.490	.356
	Entire test	**.51**	**1.00**	.500	.53	**1.00**	**.504**	**.412**

It can be seen that the mean success rate in the experimental and control group is comparable in Table 5. The H_{01} hypothesis was formulated and tested to verify this assumption.

Table 6
The Mann-Whitney U test results in post-test

Item		Experimental group			Control group			p
		$\bar{x}$	*MD*	*SD*	$\bar{x}$	*MD*	*SD*	
Items separated	Item 1	.46	.00	.498	.41	.00	.492	.251
	Item 2	.74	1.00	.438	.62	1.00	.484	.041
	Item 3	.88	1.00	.324	.93	1.00	.250	.223
	Item 4	.77	1.00	.421	.78	1.00	.415	.444
	Item 5	.71	1.00	.455	.46	.00	.499	.001
	Item 6	.68	1.00	.467	.40	.00	.490	.001
	Item 7	.96	1.00	.200	.91	1.00	.282	.251
	Item 8	.82	1.00	.386	.57	1.00	.495	.001
	Item 9	.29	.00	.455	.17	.00	.380	.039
	Item 10	.92	1.00	.266	.71	1.00	.453	.001

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Item		Experimental group			Control group			p
		$\bar{x}$	*MD*	*SD*	$\bar{x}$	*MD*	*SD*	
Items grouped	Remembering	.46	.00	.498	.41	.00	.492	.251
	Understanding	.77	1.00	.418	.68	1.00	.458	.001
	Application	.69	1.00	.464	.52	1.00	.498	.001
	Analysis	.92	1.00	.266	.71	1.00	.453	.001
Entire test		**.71**	**1.00**	**.448**	**.58**	**1.00**	**.490**	**.001**

In Table 6, it can be seen that the experimental group scored higher in the post-test than the control group. As for the cognitive process dimension measured by the post-test, the EG scored higher than the CG in all categories observed.

A comparison of pre- and post-test results in the EG listed according to the academic performance of respective students (Table 2) indicated that revising the learning content using IBSE (confirmation inquiry) was effective.

Hypotheses H_{02} to H_{04} were formulated and tested to verify these assumptions.

Hypothesis Testing

The criteria for decision making in Mann-Whitney's *U* test are as follows: if $p>.05$, H_0 is accepted; if $p<.05$, H_0 is rejected. The Mann-Whitney *U* test results for hypothesis testing can be seen in Table 7.

Table 7
Statistic verification of research hypotheses – results

Hypothesis		*z*	*p*	Description	Conclusion
H01		-.668	.412	Accepted	There is no significant difference
H02		-6.095	.001	Rejected	There is a significant difference
H03	Remembering	-.331	.251	Accepted	There is no significant difference
	Understanding	-2.410	.001	Rejected	There is a significant difference
	Analysis	-6.353	.001	Rejected	There is a significant difference
	Application	-4.012	.001	Rejected	There is a significant difference
H04	Students who achieved grade 1 in chemistry previous year	-4.388	.001	Rejected	There is a significant difference
	Students who achieved grade 2 in chemistry previous year	-4.758	.001	Rejected	There is a significant difference
	Students who achieved grades 3 or 4 in chemistry previous year	-5.726	.001	Rejected	There is a significant difference

** Level of significance=.05.*

Discussion

At the beginning of revision in September 2018, a pre-test was administered to identify the actual effect of the traditional lecture-based teaching model used previously, from February to June 2018. In the pre-test, students scored higher in remembering and understanding, but lower in the higher-order cognitive processes such as application and analysis (see Table 5). These results were comparable with Slovak students' results in the PISA 2018 international comparison measuring science literacy (OECD, 2019).

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The question was whether revising using IBSE could affect the results.

Therefore, an experiment was performed to compare the learning outcomes produced by using two different teaching methods – teaching with and without using IBSE (based on confirmation inquiry) during 10 lessons. In both groups, learning outcomes were measured using a post-test. The data obtained this way were processed to evaluate and summarise the effect of teaching methods.

1. The findings indicate that in the revision phase, the implementation of IBSE (confirmation inquiry) was more effective than teaching without using IBSE in terms of developing conceptual understanding. It was confirmed by the post-test results in which the experimental group scored better than the control group and the difference was statistically significant ($p<.001$) (see Tables 6 and 7). This result is consistent with the research results confirming the effect of IBSE strategies on improving students' conceptual understanding (Blanchard et al., 2010; Kireš et al., 2016; Kirschner et al., 2006; Minner et al., 2010; Nieswandt, 2007; Prince & Felder, 2007; Sever & Güven, 2014). The results in the cognitive process, application, and analysis show that IBSE helps develop higher-order cognitive skills (HOCS). This result relates to the fact that IBSE supports HOCS by using questions, critical thinking, and problem-solving (Anderson, 2002; Oliviera, 2010; Lemlech, 1998; Zoller, 2011).
2. According to the post-test results, the experimental group scored statistically better in the three analysed cognitive process categories: understanding, application, and analysis (see Tables 6 and 7). It relates to the fact that deeper understanding of the learning content is achieved when students learn actively (Piaget, 1973). However, no statistically significant difference between experimental and control groups was confirmed in the category of remembering. It has to do with the fact that in Slovakia, teaching aimed at remembering is preferred, which is consistent with the PISA results of 2006–2018 (OECD, 2019). These findings indicate that using IBSE to revise in teaching and learning can help Slovak students develop HOCS, which is a way to also improve their results in PISA testing.
3. Students worked in pairs or groups of 3–4; students with different academic performance were mixed to learn from each other so that higher-achieving students helped their peers who learned from them. For students who tend to be less active in front of the whole class, group work represents an opportunity to participate. The biggest statistical difference in the levels of knowledge and skills before and after the revision was identified in students with lower academic performance (grade 3–4) in the experimental group (see Table 7). These findings are consistent with the outcomes of studies confirming the influence of IBSE on academic performance (Berg et al., 2003; Pandey et al., 2011; Witt & Ulmer, 2010).

The results obtained may have been influenced by the following:

Activities verified during the pilot research and subsequently optimised were used in the revision phase (Sotáková et al., 2020).

Students in the EG obtained knowledge and skills by means of laboratory work included in the activities. It represents a suitable form of teaching in terms of IBSE application (Abrahams & Millar, 2008; Hofstein et al., 2005; Högström et al., 2010; Millar & Abrahams, 2009) as interconnecting inquiry activities with practical tasks provides a great potential to develop skills, abilities, and also scientific thinking in students.

The implementation of confirmation inquiry into teaching students in this age group may also have influenced the research results. However, the published research works have not clearly confirmed whether confirmation inquiry in teaching is effective, see e.g. Blanchard et al. (2010) who have identified significantly better post-test results in students taught using guided inquiry in comparison to students taught using confirmation inquiry. Similarly, to Lederman et al. (2008) the aforementioned research team has recommended to combine confirmation and guided inquiry. However, in this research, IBSE was used to teach secondary school students who are still considered beginners at learning, therefore they should have access to direct instructions clarifying the concepts and work procedures required by the respective subject (Clements & Battista, 1990; Mayer, 2004) – which is the goal of confirmation inquiry (Bruck et al., 2008; National Research Council, 2000; Rezba et al., 1999).

If a teacher does not have access to ready-made, verified activities, or if they have little experience in IBSE, the differences may not be that significant. As supported by research results, developing IBSE teaching skills is not easy for teachers either (Capps & Crawford, 2013; Colburn, 2000; Wallace & Kang, 2004).

The limits of using IBSE in teaching include insufficient explanation of IBSE in curricula-related documents, teachers' training in using IBSE or lack of time necessary to perform inquiry activities, and insufficient practical equipment in schools. In this research, these problems were eliminated by using verified activities that took into account the necessary amount of time (2 lessons), commonly available tools and chemicals. Further limits of this

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research included the available sample of secondary school 8-graders, the difficulty of the "Changes in chemical reactions" thematic unit, and a relatively short implementation period of IBSE into teaching.

The activities designed for the "Changes in chemical reactions" thematic unit are high quality as confirmed by the fact that they were included in the methodology guide for teaching chemistry in the 7th grade of secondary schools and 2th year of 8-year grammar schools (Vicenová & Ganajová, 2019). This manual was published with a recommendation clause from the Scientific Grant Agency of the Ministry of Education, Science, Research and Sport of the Slovak Republic. Most Slovak teachers working at secondary and 8-year grammar schools use it in teaching.

Conclusions and Implications

The presented research aimed to identify the effect of IBSE implementation (confirmation inquiry) in learning content revision on the development of conceptual understanding. Until now, no pedagogical research focused on using IBSE in revision has been published.

The findings indicate that in the revision phase, the implementation of IBSE (confirmation inquiry) was more effective than teaching without using IBSE in terms of developing conceptual understanding. A detailed analysis of the items tested showed that implementing IBSE (confirmation inquiry) helped develop the higher-order cognitive processes such as application and analysis. The statistical analysis also showed that the investigated differences were statistically significant. The implementation of IBSE (confirmation inquiry) stimulated learning mainly in students with lower academic performance (i.e. students with grades 3–4). IBSE helped these students develop conceptual understanding in the most pronounced way.

The research results confirmed the effect of using confirmation inquiry to revise and enhance understanding of the given topic in younger students.

Indirectly, it confirms that future teachers should be trained in IBSE application; before this idea is implemented in teacher training provision of quality ready-made activities could help.

The aforementioned findings suggest new tasks for the creators of educational policies and teachers in Slovakia.

Although in Slovakia, concepts such as "increasing the quality of upbringing and education", "increasing the availability of quality education and upbringing", or "modernisation of education and upbringing" are widely referred to, the actual practice is at a standstill. The requirement to implement IBSE is stipulated in the state educational programmes in Slovakia, but its application in educational practice is very slow, mainly due to the inertia of the educational system.

The creators of the educational programmes should initiate specific changes to the state educational programmes and offer specific verified activities in the respective methodology guidelines to provide teachers with guidance. Moreover, these activities should be accessible in the digital form in a central digital storage with free licences, the development of which has been contemplated in Slovakia for some time.

Last but not least, continuous specialised and methodological support for (future) teachers must be provided to help them select and adapt the learning contents and create school educational programmes. This way, students would be exposed to the long-term and complex impact of IBSE.

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Appendix

A. "Changes in chemical reactions" thematic unit: description of confirmation inquiry activities

Inquiry activity
1 Exothermic and endothermic reactions
The activity focuses on exothermic and endothermic reactions. Students investigate the thermal changes in chemical reactions of vinegar with sodium bicarbonate vs. sodium bicarbonate (solution) with calcium chloride. They enhance their knowledge of exothermic and endothermic reactions by learning about their practical use (self-heating or cooling sachets, self-heating cans).
Factors affecting the rate of chemical reactions 2 The effect of concentration on the rate of chemical reactions 3 The effect of temperature on the rate of chemical reactions **4 The effect of surface area on the rate of chemical reactions**
The goal of the activity is to verify the effect of various factors on the reaction rate between vinegar and sodium bicarbonate in practice. Students observe the course of this chemical reaction using simple apparatus (flask with a balloon on its neck). The chemical reaction rate is affected for example by diluting vinegar, increasing its temperature, or crushing the sodium bicarbonate tablet. These factors affect the speed with which the balloon is inflated by the released carbon dioxide. Students apply this knowledge to explain real-life situations such as setting fire, food storage methods, or kettle limescale removal.
5 The effect of catalysts on the rate of chemical reactions
This activity focuses on catalysts. Students verify how the presence of ash or sand affect how a sugar cube burns in practice. They enhance their knowledge about caramelisation and the function of catalytic converters in cars. They also learn about the lactase enzyme and its role in lactose digestion (milk sugar) and the reasons why lactose intolerance can emerge.

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