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The effect of the 5E instructional model on students' cognitive processes and their attitudes towards chemistry as a subject

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Abstract

The research aim was to examine the effect of the 5E instructional model on students' cognitive processes and attitudes towards chemistry as a subject. The research was performed at three Slovak grammar schools in the 1st year during the 2nd term of the 2021/2022 school year. This research employed the experimental approach with a quasi-experimental design that involved experimental and control groups. The research sample consisted of 218 students, and it was divided into two groups: the experimental group comprised 114 students (who studied using the 5E model) and the control group comprised 104 students (who studied conventionally). The intervention took place during eight lessons (four two-hour laboratory exercises). A set of inquiry-based activities for the "chemical reactions and equations" thematic unit verified via pilot research was implemented using the 5E model in the experimental group. The research used the following tools: the chemistry concepts test based on the revised Bloom's taxonomy and a questionnaire to identify the attitudes of students towards chemistry as a subject. The chemistry concepts test results indicated that teaching with the 5E model was more effective than teaching without the 5E model in terms of developing cognitive processes. It affected all the observed cognitive processes (memorization, understanding, application, analysis, and evaluation). After teaching with 5E model, students' attitudes in experimental group towards learning chemistry as a subject changed significantly. Finally, research presents some recommendations, including conducting more studies on 5E model-based strategy, cognitive processes, and attitudes towards science.

Keywords: chemistry education, 5E instructional model, cognitive processes, attitudes, grammar school

INTRODUCTION

Today's society requires a scientifically literate population that is capable of understanding current issues and deciding how to resolve them. Inquiry-based science education (IBSE) has the potential to improve the level of understanding of scientific knowledge and develop skills necessary for life in the 21st century (Chu et al., 2017). Harlen (2021) has pointed out the importance of IBSE for raising a scientifically literate population of young people who will be able to tackle major challenges related to water conservation, health, food, and energy production as well as adaptation to climate change. IBSE-based development of knowledge and skills can help students learn how to make informed decisions in their personal as well as social lives.

According to Ash et al. (2003), the inquiry process in science classes is supposed to reflect how science actually works. In this process, the teacher acts as facilitator, supporter, and feedback provider for the students (Kong & Song, 2014; Zion & Mendelovici, 2012). Depending on the amount of guidance from the teacher, the inquiry process can take place at different levels (Vorholzer & von Aufschnaiter, 2019). However, this process is always organized in specific phases, which together form a cycle of inquiry (Pedaste et al., 2015).

5E instructional model is considered one of the most commonly used and effective cycle for IBSE (Duran & Duran, 2004; Srisawasdi & Panjaburee, 2015). This model has five learning phases/stages all beginning with 'E'–engage, explore, explain, elaborate, and evaluate, and hence its name (Bybee, 2009).

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Contribution to the literature

- Teaching with 5E instructional model is more effective compared to the teacher-centered methods in terms of developing cognitive processes.
- 5E instructional model aided in the development of both the lower-order cognitive processes (memorization, understanding, and application) and the higher-order cognitive processes (analysis and evaluation).
- Students' attitudes on chemistry as a subject is positively influenced by 5E instructional model as well in the following dimensions: difficulty of chemistry, interest in chemistry, importance of chemistry for life, importance of chemistry for future career.

The results of several studies confirm that 5E model is more efficient than teacher-centered methods of instruction. It develops understanding of scientific knowledge and increases students motivation as well as their interest in studying science (e.g., Bakri & Adnan, 2021; Bezen & Bayrak, 2020; Boakye & Nabie, 2022; Bybee, 2015; Garcia et al., 2021; Gillies & Rafter, 2020; Iscan & Seyhan, 2021; Itsarangkul Na Ayutthaya & Damrongpanit, 2022; Koyunlu Unlu & Dokme, 2022; Lasaiba, 2023; Suwito et al., 2020; Varoglu et al., 2023). It promotes the development of critical thinking and argumentation skills, as well as the ability to apply the knowledge in practice (Amaliyah et al., 2023; Cahyarini et al., 2016; Chen, 2021; Chu et al., 2017; Ha et al., 2023; Miarti et al., 2021; Vafaeikia et al., 2023). It also facilitates the development of inquiry skills or scientific process skills (Cakir, 2017; Ergul, 2011; Harlen, 2021; Ješková et al., 2022; Liu et al., 2021; Ozkul & Ozden, 2020; Tolba & Al-Osaimi, 2023; Wale & Bishaw, 2020) such as formulation of research questions and hypotheses, provision of evidence, evaluation of explanations, and conclusion-drawing. Moreover, the 5E model promotes the development of scientific literacy (Areepattamannil et al., 2020; Bybee, 2019). It also improves the learning atmosphere and allows students to take over their own learning (Maxwell et al., 2015) and express their ideas and opinions (Bezen & Bayrak, 2020). The 5E model also has effect on long-term learning (Garcia et al., 2021; Koyunlu Unlu & Dokme, 2022).

5E Instructional Model and Cognitive Processes According to Revised Bloom's Taxonomy

Taxonomies of educational objectives are very useful for planning teacher and student activities and provide guidance in teaching.

Revised Bloom's taxonomy has two dimensions: cognitive processes and knowledge (Anderson & Krathwohl, 2001). She refers to six levels of cognitive process, ranked from the lowest to the highest. Memorization, understanding, and application, are classified as lower-order cognitive processes, while analysis, evaluation and creating are classified as higher-order cognitive processes. The individual levels overlap and are interconnected, i.e., developing a higher-order cognitive process requires having developed the preceding, lower one. The knowledge dimension consists of four types of knowledge: factual, conceptual, procedural, and metacognitive. These two dimensions can be used separately or combined (Radmehr & Drake, 2019).

The effect of 5E model on the development of higher-order cognitive processes according to Bloom ("analysis, evaluation, and creating") has only been investigated to a limited extent so far. This information results from the systematic review performed by Koyunlu Unlu and Dokme (2022) in which the authors analyzed 56 empirical studies. Their findings indicate a positive influence of 5E model on the lower-order cognitive processes (memorization, understanding). Only 17 studies (23%) investigated this model's effect on the higher-order cognitive processes (analysis, evaluation, and creating), which are important in science teaching. The authors argue that the development of higher-order cognitive processes via 5E model is problematic. However, this model can have a significant effect on the development of higher-order cognitive processes if two conditions are met. The first condition is that 5E model's structure must incorporate higher-order cognitive skills. In our research, this condition was met–suitable inquiry activities were designed (**Appendix A** and **Appendix B**). The second condition is that the effect of the model is measured by instruments that can verify the cognitive output related to higher-order cognitive processes. This condition was met as well since we applied a standardized concept test, which comprised tasks focused on verifying the development of lower as well as higher-order cognitive processes (National Institute for Certified Educational Measurements [NICEM], 2015).

According to Koyunlu Unlu & Dokme (2022), the 5E model develops all levels of cognitive processes pertaining to Blooms revised taxonomy (**Table 1**).

Research Problem

Slovakia is one of the countries, where teacher-centered methods still prevail (Balansag, 2018; Saritas, 2016).

In Slovakia, systematic efforts to implement IBSE first appeared in the beginning of the education reform in 2008, when the concept of inquiry was explicitly

Table 1. Characteristics of 5E model phases (Ash et al., 2003; Bybee, 2015, 2019; Duran & Duran, 2004; Srisawasdi & Panjaburee, 2015) and associated cognitive processes (Koyunlu Unlu & Dokme, 2022; Kruse, 2009)

Characteristic	Definition	Phase
Engage	Students observe something that sparks their interest and inspires them to ask questions about new information that makes or does not make sense to them based on their previous experience and understanding.	Memorization
Explore	Formulation of questions & predictions, their verification & testing, creation of a theory or model. Students explore links between different components & their understanding of subject matter is enhanced. In this phase, students use multiple sources (material, technical, information), present information gathered in a variety of forms, and communicate with other participants (classmates, teacher, practical expert).	Understanding application analysis
Explain	Drawing reasonable conclusions & formulating explanations–consideration, group discussion, comparing findings with others, interpretation of information gathered.	
Elaborate	Application of newly acquired knowledge to different contexts. These activities help students integrate their newly acquired knowledge into existing structure of their knowledge.	Evaluation creating
Evaluate	This is both a separate phase and an activity performed throughout other phases within the learning cycle. Students' knowledge, abilities, and skills are evaluated. Tools useful for evaluating the extent to which students have achieved their goals include, for example, tests, laboratory protocols, presentations, portfolios, and mind maps. Self-assessment and peer-assessment can be used as well.	

included in the state educational programs for physics, chemistry, and biology (ISCED 2 and ISCED 3) (Kireš et al., 2016). Although the Slovak national curriculum emphasizes the inquiry-based approach to science teaching, teachers lacked supporting materials for the implementation of IBSE. Traditional teacher-centered methods were and still are dominant in schools and preferred by teachers.

In the long term, it reflects in the OECD PISA results (program for international student assessment). The OECD PISA results indicate that Slovak students acquire a large quantity of knowledge including theory and are able to formulate brief explanations and make decisions, but they find it difficult to study scientific phenomena independently and contextually, build hypothesis, seek and propose solutions, interpret findings, draw conclusions, and support their ideas with arguments (Miklovičová & Valovič, 2019). Slovak students experience difficulties with completing tasks that require application of higher-order cognitive processes (Kosturková et al., 2018). This points out a major issue in the Slovak curriculum, namely the excessive emphasis on the acquisition of theoretical and encyclopedic knowledge. Comparative studies performed at primary and grammar schools in the EU countries (e.g., Miklovičová et al., 2017; OECD, 2016; Osborne & Dillon, 2008; Potvin et al., 2017) have shown that students' lack of interest in science results relates to the teacher-centered methods used in science teaching, which do not appeal to students.

In 2010-2018, IBSE started gaining more recognition because Slovak educational institutions and universities actively participated in international projects such as ESTABLISH, SAILS, PRIMAS, Fibonacci, and CHREACT, which developed many teaching/learning materials (TLM) focused on inquiry activities using the 5E model in natural sciences (Kireš et al., 2016). The IT academy–education for the 21st century project (2016–2021, https://itakademia.sk/) built on these efforts and allowed for the creation of more TLM using the 5E model for physics, chemistry, biology, mathematics, and computer science (ISCED 2 and ISCED 3). These TLM have been used by teachers since 2016 thanks to numerous trainings for teachers aimed at introducing IBSE-based TLM into the teaching process. The question was how such TLM would affect the level of cognitive processes in students, and students' attitudes to science subjects.

Research Aim and Research Questions

The aim of the research was to determine whether 5E model develops cognitive processes in students, and whether 5E model affects students' attitudes to chemistry as a subject.

The use of 5E model represented an independent research variable.

The research was performed in chemistry lessons, specifically "chemical reactions and equations" thematic unit taught in the 1st year of the selected grammar schools.

This study addressed the following research questions:

1. How does using the 5E model influence students' on specific levels of cognitive processes?
2. How does using the 5E model affect students' attitudes towards chemistry as a subject?

Research Hypotheses

The following hypotheses were formulated and tested.

Table 2. Characteristics of experimental & control group

		Experimental group		Control group	
		Number of students	Percentage	Number of students	Percentage
Chemistry grade in midterm report card	Students with grade 1	44	38.6	44	42.3
	Students with grade 2	48	42.1	40	38.5
	Students with grade 3	22	19.3	20	19.2
Total		114	100.0	104	100.0

Note. Grades 4 and 5 did not occur in the midterm reports

H1. There are no statistically significant differences (level of significance=0.05) between students' mean scores in the experimental vs. control groups in the chemistry concepts test.

H2. There are no statistically significant differences (level of significance=0.05) between students' mean scores in the experimental vs. control groups in the pre-applied questionnaire, which identifies their attitudes toward chemistry as a subject.

H3. There are no statistically significant differences (level of significance=0.05) between students' mean scores in the experimental vs. control groups in the post-applied questionnaire, which identifies their attitudes toward chemistry as a subject.

RESEARCH METHODOLOGY

Research Approach

To achieve the research objectives, the experimental approach with a quasi-experimental design was used (Shadish et al., 2002). It was based on administering the concepts test and questionnaire to two groups. The experimental group was taught using the 5E model while the control group was not.

Research Sample

The research was performed in three grammar schools located in two Slovak cities (Prešov and Košice) in the second term of the 2021/2022 school year (January-March). The selection of schools and teachers was deliberate. Each school allowed for two parallel 1st year forms to participate in the research. The forms were divided into control and experimental groups based on two criteria. The first criterion was the average grade in chemistry on the midterm report card. The second criterion was the outcome of the standardized inquiry skill test (Ješková et al., 2016, 2022). This test was used due to the following reasons: The subject matter addressed during the first term of the 1st year of a grammar school requires memorization and understanding (structure of atoms and ions, periodic table of elements, nomenclature of inorganic compounds, chemical bonding and structure of substances). On the other hand, the subject matter (chemical reactions and equations) addressed during the 2nd term requires students to apply higher-order cognitive processes such as application, analysis, and evaluation.

Inquiry skill test results showed that all forms were at a statistically similar level at the beginning ($p>0.05$). Therefore, parallel forms in different schools were assigned to the control and experimental groups randomly. Equality of the groups was also confirmed by the weighted average grade in chemistry in students' midterm report cards (experimental group mean $M=1.81$ vs. control group $M=1.77$).

The research sample consisted of 218 students in total. The students were aged 15 to 16. The experimental group consisted of 114 (52.3%) students and the control group of 104 (47.7%) students. **Table 2** shows the number and percentage of the students based on their chemistry grades on their midterm report cards (1=excellent performance to 5=underachievement).

Teacher Preparation

Both parallel forms were taught chemistry by the same teacher. All three teachers (with more than 15-year practice) who participated in this research took the same course entitled "teaching chemistry at grammar schools with the focus on developing digital and science literacy". The combined (on-line and on-site) course consisted of four lectures and two workshops/working seminars and took 16 hours in total. During this course, teachers learned how to implement 5E model and made themselves familiar with the inquiry activities addressing a variety of topics in line with the educational standard for teaching chemistry at grammars schools (National Institute for Education, Slovakia [NIE], 2014).

Preparation of Experimental Processing Tools and Measurements

The preparation of the experimental processing tools involved the following steps:

1. **Choosing the educational content:** In the 1st year of grammar school, there are three chemistry lessons per week, i.e., 99 lessons per term. Every two weeks, there are laboratory lessons, and the class is divided into two groups. "Chemical reactions and equations" thematic unit is taught in the second term. The formal SA standard (NIE, 2014) includes the following topics (**Table 3**).

Table 3. Formal SA standard for "chemical reactions and equations" thematic unit (NIE, 2014)

Content standards
Chemical reaction, reactants, products, chemical equation, law of conservation of mass in chemical reactions, stoichiometric coefficient, exothermic and endothermic reaction, reaction heat, rate of chemical reaction, factors affecting the rate of chemical reactions (concentration of reactants, temperature, catalyst, surface area of solids), reversible reaction, chemical equilibrium, equilibrium concentration of substances, factors affecting chemical equilibrium (concentration of substances, temperature, pressure), proteolytic reaction, strong and weak acid/base, pH, pH scale, acidic, neutral and basic solution, neutralization, salt, indicator.
Performance standards
• Write down a chemical reaction using a chemical equation, determine stoichiometric coefficients based on the law of conservation of mass. • Distinguish between endothermic and exothermic reactions based on observation or formula, provide real-life examples of exothermic and endothermic reactions. • Compare the rate of chemical reactions based on observation, give real-life examples of slow and fast chemical reactions; explain the effects of temperature change, reactant concentration change, solid reactant surface size, and catalysts on rate of a chemical reaction; perform an experiment to verify effect of factors on the rate of a chemical reaction. • Explain the effect of adding reactant or removing product, the effect of change in temperature and pressure on the equilibrium state of a system. • Give examples of strong and weak acids and bases, distinguish between an oxonium cation and a hydroxide anion, use pH indicators to determine the acidity or basicity of a solution, classify solutions as acidic, neutral, and basic according to their pH value, write a chemical equation for neutralization, list examples of practical applications of neutralization.

2. **Preparation of inquiry activities:** In accordance with the formal SA standard for "chemical reactions and equations" thematic unit, a set of four inquiry activities was developed (exothermic and endothermic reactions, factors affecting the rate of chemical reactions, effect of temperature on equilibrium, and how carbon dioxide affects the pH of solutions). All activities (**Appendix A**) were designed in accordance with the 5E model (Bybee, 2009) for the confirmatory inquiry level (ESTABLISH, 2011). Each inquiry activity was designed for two lessons.

The developed set of inquiry activities was verified on a sample of 57 students and three teachers during the pilot research performed in the 2017/2018 school year. The design-based research (DBR) methodology was used in this study. Based on the results of this research, the activities were modified.

"Exothermic and endothermic reactions" inquiry activity was selected for demonstration (**Appendix B**). The goal of this activity was to perform and evaluate an experiment with exothermic and endothermic reactions. The temperature change of the reaction system was monitored during the reactions of vinegar with sodium bicarbonate and sodium bicarbonate (solution) with calcium chloride (waterless). The students worked in pairs. Their activities were guided by the tasks in the work sheets (based on the 5E model). During the activity, the teacher motivated and guided students by asking suitable questions.

Research Tools

Inquiry skills test

The inquiry skills test was aimed at identifying the level of students' inquiry skills. Based on the inquiry skills test results, students were assigned to the experimental and control groups respectively.

The test was developed based on the available inquiry skills testing instruments (Burns et al., 1985; Gormally et al., 2012; Wenning, 2007) and inquiry skills taxonomies (Fradd et al., 2015; Tamir & Lunetta, 1981; Van den Berg, 2013).

The test consisted of 14 items and focused on these inquiry skills: designing experiments, formulating hypothesis, transforming data into tables and graphs, identifying relationships between variables based on tables and graphs, and identifying sources of errors. At least two items were allocated to each skill. The item context drew from the subject matter taught in the main science subjects (physics, chemistry, biology). The maximum score represented 14 points. A detailed description of the test design can be found in Ješková et al. (2016; 2022).

Pilot verification of the inquiry skills test

The test was administered to a pilot sample consisting of 57 students (who were not part of this research sample) to calculate its reliability. The reliability of the inquiry skills test was calculated using the Cronbach's alpha (Cronbach, 1951) and equaled to α=0.692, which is an acceptable reliability coefficient.

The internal consistency of the inquiry skills test was validated by calculating the correlation between the scores of each test item and the respective dimensions. The values ranged between 0.350 and 0.672. The mutual correlations between individual skills and the total test score was determined as well (0.345-0.854) using the Pearson correlation coefficient. Statistically significant correlation coefficients at the significance level 0.05 and 0.01 indicate that this test is internally consistent.

Chemistry concepts test

The chemistry concepts test aimed at identifying the level of knowledge and cognitive processes within "chemical reactions and equations" thematic unit in students pertaining to both groups after being taught with vs. without the 5E model.

The chemistry concepts test (**Appendix C**) consisted of 15 items focused on different domains of the revised Bloom's taxonomy (Anderson & Krathwohl, 2001). It included the learning content of "chemical reactions and equations" thematic unit in accordance with the content and performance standards defined in the formal SA standard (NIE, 2014). The items related to

(a) **knowledge dimension:** factual (three items), conceptual (seven items), and procedural (five items), and

(b) **cognitive process dimension:** memorization (three items), understanding (three items), application (four items), analysis (three item), and evaluation (two items) (**Table 4**).

Table 4. Chemistry concepts test items based on revised Bloom's taxonomy

Item no	Category: Knowledge dimension	Category: Cognitive process
1	Factual	Memorization
2	Conceptual	Memorization
3	Procedural	Memorization
4	Factual	Understanding
5	Factual	Understanding
6	Conceptual	Understanding
7	Conceptual	Application
8	Conceptual	Application
9	Procedural	Application
10	Procedural	Application
11	Conceptual	Analysis
12	Procedural	Analysis
13	Procedural	Analysis
14	Conceptual	Evaluation
15	Conceptual	Evaluation

In terms of task type, the test included 10 single-choice questions and five short open questions. 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. Each correct answer was assigned one point; thus, students could achieve maximum of 15 points.

Pilot verification of the chemistry concepts test

The test was administered to a pilot sample consisting of 57 students (who were not part of this research sample) to calculate its reliability.

The reliability of the chemistry concepts test was calculated using the Cronbach's alpha (Cronbach, 1951); α=0.701 is an acceptable reliability coefficient.

The internal consistency of the chemistry concepts test was calculated to determine the correlation between the scores of each item and the respective cognitive dimension; the values ranged between 0.235 and 0.714.

The mutual correlations between cognitive dimensions and the total score of the test ranged between 0.369 and 0.872, which was calculated using the Pearson correlation coefficient, i.e., statistically significant correlation coefficients at the level of significance 0.05 and 0.01 indicate that this test is internally consistent as well.

Both tests took approximately 45 minutes.

Questionnaire focused on students' attitudes towards chemistry as a subject

The questionnaire was used to identify the attitudes of the students of both groups towards chemistry as a subject before and after being taught with vs. without 5E model.

The attitudes were identified using a modified questionnaire from the ESTABLISH project (Kekule & Žák, 2014). The questionnaire consisted of two modules. Module A focused on the basic information on the respondents/students. Module B included 12 items divided into four dimensions: difficulty of chemistry, interest in chemistry, importance of chemistry for life, and importance of chemistry for future career (see Research Results). In this module, respondents/students expressed their attitudes using a 5-point Likert scale (1=strongly disagree; 2=disagree; 3=I do not know; 4=agree; 5=strongly agree).

Pilot verification of the questionnaire

The questionnaire was applied to a pilot sample consisting of 57 students (who were not part of this research sample) to calculate its reliability.

The reliability of the questionnaire expressed as the Cronbach's alpha coefficient (Cronbach, 1951) was sufficient: α=0.813, which is a high and acceptable reliability coefficient.

The internal consistency of the questionnaire was calculated to determine the correlation between the scores of each questionnaire item and the respective dimension; the values ranged between 0.263 and 0.724. The mutual correlations between individual dimensions and their correlation with the total score ranged between 0.372 and 0.883 (Pearson correlation coefficient was used). The statistically significant correlation coefficients at the level of significance 0.05 and 0.01 indicate that this test is internally consistent.

The appropriate time for the questionnaire is 20 minutes.

Procedures

Assignment of students into control and experimental groups

In January 2022, the inquiry skills test was administered to assign the students into the experimental and control groups. The goal was to compare their overall level of inquiry skills. The inquiry skills test results confirmed that all forms were at a statistically similar level ($p>0.05$). Therefore, parallel forms in different schools were assigned to the control and experimental groups randomly. In terms of the (experimental) intervention, the 5E model was implemented into teaching in the experimental group. Equivalence of the default starting point for the development of higher-order cognitive processes was ensured.

Teaching with vs. without 5E model

Subsequently, both groups proceeded to study "chemical reactions and equations" thematic unit (January to March 2022). The experimental group was taught using 5E model while in the control group 5E model was not used at all. In the experimental group, four inquiry activities (**Appendix A**) were performed during laboratory exercises. In the control group, the teachers used the laboratory exercises provided in the chemistry course book for the 1st year of grammar schools (Kmeťová et al., 2010). Both groups completed 4 two-hour laboratory exercises. During laboratory exercises, the students worked in pairs.

Verification of teaching efficiency

After completing "chemical reactions and equations" thematic unit, all students completed the chemistry concepts test.

To identify how teaching with vs. without the 5E model influenced students' attitude toward chemistry as a subject, both experimental and control groups were administered the same scale questionnaire for the second time, i.e., before the experiment and three months later.

Data Analysis

Chemistry concepts test

The normality of data distribution was verified for overall test scores; items were grouped into dimensions (memorization, understanding, application, analysis, and evaluation) and also assessed separately using the Kolmogorov-Smirnov test. In all cases, $p<0.001$ suggested that the data obtained were not normally distributed, therefore the non-parametric Mann-Whitney U test for two independent samples was used to compare the scores in the experimental vs. control groups.

Questionnaire focused on students' attitudes towards chemistry as a subject

The normality of data distribution was verified for overall score in the questionnaire; items were grouped into dimensions (D1–difficulty of chemistry, D2–interest in chemistry, D3–importance of chemistry for life, D4–importance of chemistry for future career) and also assessed separately using the Kolmogorov-Smirnov test. In all cases, $p<0.001$ suggested that the data obtained were not normally distributed, therefore the paired samples Wilcoxon test was applied to establish whether there was a significant difference in the pre- and post-application of the questionnaire.

All statistical analyses were performed using SPSS v. 18 (SPSS Inc., 2009). For all statistical analyses, a value of $p<0.05$ was considered significant.

RESULTS

Basic descriptive statistics pertaining to the inquiry skills test results in both groups is shown in **Table 5**.

Table 5. Inquiry skills test results

	Experimental group		Control group	
	M	SD	M	SD
Total	.373	.188	.368	.176

Note. M: Mean & SD: Standard deviation

The results in **Table 5** show that the overall level of inquiry skills failed to match the relative score of 0.4. The results of this test indicate that students' level of inquiry skills was low. It may be caused by the fact that the teacher-oriented teaching style prevails at many Slovak schools. In the inquiry skills test, no statistically significant difference was found between the experimental and control groups ($p=0.063$, therefore $p>\alpha$). This fact was important for the experimental intervention.

First Hypothesis

The first hypothesis was formulated as follows: There are no statistically significant differences (level of significance=0.05) between students' mean scores in the experimental vs. control groups in the chemistry concepts test.

In **Table 6**, the mean scores of the experimental and control groups in the chemistry concepts test and its sub-dimensions are presented.

Table 6. Results of chemistry concepts test & its sub-dimensions

Item		Experimental group			Control group			p-value	Significance
		Mean	Median	SD	Mean	Median	SD		
Items separated	Item 1	.83	1.00	.343	.77	1.00	.421	.209	Not significant
	Item 2	.87	1.00	.335	.58	1.00	.494	.001	Significant
	Item 3	.96	1.00	.176	.92	1.00	.266	.453	Not significant
	Item 4	.87	1.00	.335	.92	1.00	.266	.862	Not significant
	Item 5	.71	1.00	.355	.46	.00	.498	.001	Significant
	Item 6	.81	1.00	.357	.42	.00	.494	.001	Significant
	Item 7	.87	1.00	.335	.46	.00	.498	.001	Significant
	Item 8	.74	1.00	.437	.73	1.00	.443	.606	Not significant
	Item 9	.87	1.00	.335	.65	1.00	.475	.001	Significant
	Item 10	.56	1.00	.486	.55	1.00	.483	.400	Not significant
	Item 11	.84	1.00	.347	.63	1.00	.490	.001	Significant
	Item 12	.71	1.00	.453	.65	1.00	.475	.001	Significant
	Item 13	.50	1.00	.503	.27	.00	.443	.001	Significant
	Item 14	.81	1.00	.357	.35	.00	.486	.001	Significant
	Item 15	.81	1.00	.357	.65	1.00	.475	.001	Significant
Items grouped	Memorization	.89	1.00	.304	.76	1.00	.403	.001	Significant
	Understanding	.80	1.00	.349	.60	1.00	.429	.001	Significant
	Application	.76	1.00	.408	.60	1.00	.475	.001	Significant
	Analysis	.68	1.00	.434	.52	1.00	.469	.001	Significant
	Evaluation	.81	1.00	.357	.50	1.00	.481	.001	Significant
Entire test		.79	1.00	.367	.60	1.00	.448	.001	Significant

Note. SD: Standard deviation

Table 7. Statistic verification of **H1** research hypothesis–Results of Mann-Whitney U test

Hypothesis	Group (n)	Mean rank	Sum of ranks	Mann-Whitney U	Z	p-value	Significance
H_1 (chemistry concepts test)	EG (114)	79.58	9072.00	2312.000	-4.225	.001	Significant
	CG (104)	64.24	6681.00				
Memorization	EG (114)	82.86	9446.00	2278.500	-2.766	.001	Significant
	CG (104)	80.41	8363.00				
Understanding	EG (114)	72.82	8302.50	2344.500	-2.996	.001	Significant
	CG (104)	61.20	6365.00				
Application	EG (114)	76.81	8756.50	2351.500	-2.655	.001	Significant
	CG (104)	68.25	7098.00				
Analysis	EG (114)	77.45	8829.50	2300.500	-2.866	.001	Significant
	CG (104)	56.54	5880.50				
Evaluation	EG (114)	79.58	9072.50	2003.500	-5.326	.001	Significant
	CG (104)	65.89	6853.00				

Note. EG: Experimental group & CG: Control group

Table 6 shows that in chemistry concepts test experimental group scored higher than control group. As for cognitive process measured by test, experimental group scored higher than the control group in all categories. The presented results indicate that teaching the subject matter using 5E model was efficient.

The H1 hypothesis was tested to verify these suppositions. Results of Mann-Whitney U test for **H1** can be seen in **Table 7**.

Table 7 indicates there are statistically significant differences at 0.05≥α between the mean scores in the experimental vs. the control groups in the chemistry concepts test as a whole, and in its different cognitive levels favoring the experimental group. Therefore, the null hypothesis was rejected, and an alternative hypothesis was formulated: "There is a statistically significant difference at the level 0.05≥α between the mean scores in the experimental vs. control groups in the chemistry concepts test as a whole and its dimensions (memorization, understanding, application, analysis, synthesis, and evaluation)."

Second and Third Hypothesis

The second hypothesis was formulated as follows: "There are no statistically significant differences (level of significance=0.05) between students' mean scores in the experimental vs. control groups in the pre-applied questionnaire, which identifies their attitudes toward chemistry as a subject."

The third hypothesis was formulated as follows: "There are no statistically significant differences (level of significance=0.05) between students' mean scores in the

Table 8. Wilcoxon test for paired samples results (pre- & post-application of the questionnaire)–experimental group

D	Item	Pre-application		Post-application		Z	p-value	SG
		Mean	SD	Mean	SD			
D1	1. I find chemistry quite easy.	2.74	1.319	3.16	1.080	-5.91	.001	S
D2	2. Chemistry is interesting.	2.85	.971	4.01	.782	-5.41	.001	S
D2	3. I like chemistry better than most other subjects.	2.29	1.083	2.77	.968	-7.11	.001	S
D2	4. Chemistry has increased my curiosity about the things we cannot explain yet.	3.00	1.016	3.42	.975	-3.21	.001	S
D2	5. I would like to have as much chemistry as possible at school.	2.55	1.433	3.00	1.016	-6.21	.001	S
D3	6. I think everybody should learn chemistry at school.	2.61	1.311	3.04	.831	-6.21	.001	S
D3	7. The things that I learn in chemistry at school will be helpful in my everyday life.	3.06	1.109	3.39	.859	-2.78	.001	S
D3	8. Chemistry has made me more critical & skeptical.	2.26	1.063	3.04	.831	-9.68	.001	S
D3	9. Chemistry has shown me importance of science for life.	3.36	.934	3.75	.801	-4.91	.001	S
D4	10. Thanks to chemistry, I have learned about new and interesting professions.	2.23	1.055	2.81	.930	-7.98	.001	S
D4	11. I think that learning chemistry at school will improve my career chances.	2.58	1.476	3.06	.800	-6.88	.001	S
D4	12. I would like to become a scientist.	2.19	1.305	2.51	1.240	-4.08	.001	S

Note. D: Dimension; SD: Standard deviation; SG: Significance; S: Significant; D1: Difficulty of chemistry; D2: Interest in chemistry; D3: Importance of chemistry for life; & D4: Importance of chemistry for future career

Table 9. Wilcoxon test for paired samples results (pre- & post-application of the questionnaire)–control group

D	Item	Pre-application		Post-application		Z	p-value	SG
		Mean	SD	Mean	SD			
D1	1. I find chemistry quite easy.	2.63	1.314	2.76	.980	-1.69	.081	NS
D2	2. Chemistry is interesting.	2.75	.830	3.05	1.082	-2.98	.021	S
D2	3. I like chemistry better than most other subjects.	2.35	1.073	2.47	1.268	-2.11	.067	NS
D2	4. Chemistry has increased my curiosity about the things we cannot explain yet.	2.85	1.170	3.02	.955	-1.71	.074	NS
D2	5. I would like to have as much chemistry as possible at school.	2.48	1.093	2.67	1.316	-2.71	.121	NS
D3	6. I think everybody should learn chemistry at school.	2.53	1.423	2.86	1.400	-2.88	.001	S
D3	7. The things that I learn in chemistry at school will be helpful in my everyday life.	3.11	1.059	3.19	1.059	-0.78	.201	NS
D3	8. Chemistry has made me more critical & skeptical.	2.31	1.063	2.44	.931	-1.68	.083	NS
D3	9. Chemistry has shown me importance of science for life.	3.08	.873	3.25	.971	-1.73	.071	NS
D4	10. Thanks to chemistry, I have learned about new and interesting professions.	1.92	1.355	2.11	1.230	-1.88	.063	NS
D4	11. I think that learning chemistry at school will improve my career chances.	2.69	1.321	2.74	1.331	-.21	.231	NS
D4	12. I would like to become a scientist.	1.99	1.205	2.15	1.250	-1.68	.074	NS

Note. D: Dimension; SD: Standard deviation; SG: Significance; S: Significant; NS: Not significant; D1: Difficulty of chemistry; D2: Interest in chemistry; D3: Importance of chemistry for life; & D4: Importance of chemistry for future career

experimental vs. control groups in the post-applied questionnaire, which identifies their attitudes toward chemistry as a subject."

Questionnaire items were grouped into four dimensions: D1–difficulty of chemistry, D2–interest in chemistry, D3–importance of chemistry for life, and D4–importance of chemistry for future career.

Differences in students' attitudes towards chemistry as a subject were measured, and pre- and post-application of the questionnaire results were compared and analyzed using Wilcoxon test for paired samples. Wilcoxon test for paired samples values in experimental and control group are listed in **Table 8** and **Table 9**.

The results in **Table 8** indicate a statistically significant improvement in all 12 questionnaire items for the experimental group in the post-application. Standard deviations in all answers to the post-application of the questionnaire decreased, which indicates that the variability of the students' answers decreased.

The post-application results in **Table 9** indicate a statistically significant improvement in only two questionnaire items for the control group. Standard deviations in some answers to the post-questionnaire increased, which indicates that the variability of the students' answers increased as well.

Table 10. Results of pre-application of the questionnaire & its sub-dimensions

Dimension	Group	Mean	Standard deviation	Z	p-value	Significance
D1–Difficulty of chemistry	EG	2.740	1.319	-2.13	.060	Not significant
	CG	2.630	1.314			
D2–Interest in chemistry	EG	2.673	1.125	-2.11	.063	Not significant
	CG	2.560	1.112			
D3–Importance of chemistry for life	EG	2.823	1.104	-.68	.221	Not significant
	CG	2.758	1.105			
D4–Importance of chemistry for future career	EG	2.333	1.279	-1.67	.082	Not significant
	CG	2.200	1.294			
Pre-application of the questionnaire	EG	2.652	1.207	-1.65	.078	Not significant
	CG	2.537	1.206			

Note. EG: Experimental group & CG: Control group

Table 11. Results of post-application of the questionnaire & its sub-dimensions

Dimension	Group	Mean	Standard deviation	Z	p-value	Significance
D1–Difficulty of chemistry	EG	3.160	1.080	-4.81	.001	Significant
	CG	2.760	.980			
D2–Interest in chemistry	EG	3.300	.936	-6.78	.001	Significant
	CG	2.803	1.155			
D3–Importance of chemistry for life	EG	3.305	.831	-4.78	.001	Significant
	CG	2.935	1.090			
D4–Importance of chemistry for future career	EG	2.793	.990	-6.31	.001	Significant
	CG	2.333	1.270			
Post-application of the questionnaire	EG	3.140	.959	-5.57	.001	Significant
	CG	2.707	1.123			

Note. EG: Experimental group & CG: Control group

The differences between the experimental and control groups in the pre- and post-application of the questionnaire and its sub-dimensions are listed in **Table 10** and **Table 11**.

Table 10 shows no statistically significant differences between the mean scores in the experimental vs. control groups in pre-application of the questionnaire and its sub-dimensions, which confirms that these groups are equivalent. This suggests that the null hypothesis can be accepted. There are no statistically significant differences at the significance level 0.05 between the mean scores in the experimental vs. control groups in the pre-application of the questionnaire focused on students' attitudes toward chemistry as a subject.

Table 11 shows statistically significant differences at $0.05 \geq \alpha$ between the mean scores in the experimental vs. control groups on post-application of the questionnaire and its sub-dimensions. This suggests that the null hypothesis should be rejected and an alternative hypothesis formulated: "There are statistically significant differences (level of significance $0.05 \geq \alpha$) between the mean scores in the experimental vs. control groups in the post-application of the questionnaire focused on students' attitudes toward chemistry as a subject and its sub-dimensions (difficulty of chemistry, interest in chemistry, importance of chemistry for life, importance of chemistry for future career)."

DISCUSSION

The research aim was to examine the effect of the 5E instructional model on the development of students' cognitive processes as well as their attitudes to chemistry as a subject.

It was performed in terms of teaching "chemical reactions and equations" thematic unit in the 1st year of grammar schools. The choice of the thematic unit was deliberate. It was identified as the problematic, yet key learning content in the chemistry curriculum at upper secondary schools (Rychtera et al., 2020).

At the beginning of this research, the students' overall level of inquiry skills was determined in all participating forms. For this purpose, a standardized inquiry skills test was used (Ješková et al., 2016; 2022). The inquiry skills test results showed a low overall level of students' inquiry skills. All forms were at a statistically comparable level ($p>0.05$). Therefore, parallel forms in different schools were allocated to the control and experimental groups randomly. No statistically significant difference was identified between the experimental and control groups in the inquiry skills test ($p=0.063$) (**Table 5**). This distribution was confirmed by a second parameter, i.e., the students weighted average midterm grade in chemistry (**Table 2**). These facts were important for the experimental intervention.

Subsequently, teaching was carried out in the experimental and control groups. The experiment was performed to compare the teaching/learning achievements obtained by using two different teaching methods: teaching using the 5E model and without it during eight lessons (four two-hour laboratory exercises). In both groups (experimental and control), the teaching/learning achievements were measured by a chemistry concepts test.

The presented findings imply that teaching using the 5E model was more efficient than teaching without the 5E model in the development of cognitive processes. The chemistry concepts test results confirmed this as the experimental group scored better than the control group with a statistically significant difference ($p<0.001$) (**Table 7**). According to the chemistry concepts test results, the experimental group scored statistically better in all analyzed cognitive processes: memorization, understanding, application, analysis, and evaluation (**Table 6** and **Table 7**). These findings indicate that teaching using the 5E model helps student develop higher-order cognitive processes as well. It can be stated based on the fact that the two conditions specified by Koyunlu Unlu and Dokme (2022) were met. The structure of the inquiry activities designed (**Appendix A** and **Appendix B**) required application of the higher-order cognitive skills; the efficiency of the 5E model was measured by a standardized chemistry concepts test, which included tasks focused on the verification of higher-order cognitive processes as well (**Appendix C**).

Our results are in line with the results of previous studies focused on the importance of using the 5E model because it helps develop lower as well as higher-order cognitive processes (e.g., Abdi, 2014; Areepattamannil et al., 2020; Freeman, 2014; Hugerat & Kortam, 2014; Mubarok et al., 2019; Ong et al., 2018; Ramlee et al., 2019; Shivam & Mohalik, 2022; Suryanti et al., 2018; Ugwuanyi et al., 2023; Wale & Bishaw, 2020; Zohar, 2000; Zohar & Dori, 2003; Zoller, 2011). The 5E model exposes students to problem situations (i.e., engages student thinking) and then provides opportunities to explore, explain, extend, and evaluate their learning. Overall, one could argue that the 5E model is effective because students are provided with several opportunities to deeply engage with the learning in a way that promotes connections between what is known and what is meant to be learned (Ruiz-Martín & Bybee, 2022).

The attitudes of students pertaining to both groups to chemistry as a subject was determined using a pre- and post-application of the questionnaire. The obtained data were statistically processed to evaluate and summarize the effect of the teaching methods. By comparing the results of the experimental and control groups in the pre-application of the questionnaire, no statistically significant differences ($p>0.05$) in the students' attitudes towards chemistry as a subject were identified, which confirms the equivalence of the two groups (**Table 10**). By comparing the results of the experimental and control groups in the post-application of the questionnaire, statistically significant differences ($p\leq0.05$) in the students' attitudes towards chemistry as a subject were identified (**Table 11**). The statistically significant differences in students' attitudes were confirmed in all analyzed dimensions: D1–difficulty of chemistry, D2–interest in chemistry, D3–importance of chemistry for life, D4–importance of chemistry for future career. This proved that the implementation of inquiry activities with the 5E model had a positive impact on students' attitude toward chemistry as a subject. These findings indicate that teaching with the 5E model influences students' attitudes on the importance of chemistry and science in general, which is in line with other studies (e.g., Aguilera & Perales-Palacios, 2020; Bezen & Bayrak, 2020; Guven et al., 2020; Guzel, 2017; Jiang & McComas, 2015; Kang & Keinonen, 2017; Lin et al., 2014; Nicol et al., 2022; Ozkul & Ozden, 2020; Potvin et al., 2017; Savelsbergh et al., 2016; Wiriani & Ardana, 2022). The positive effect of IBSE on the "affective" results such as students' attitude to learning science was also identified by Ergul et al. (2011), Gibson and Chase (2002), Potvin and Hasni (2014), and Wolf and Fraser (2008). According to some authors (Maltese & Tai, 2011), mainly in the long run (Ma & Kishor, 1997; Singh et al., 2002), the affective results are more important than cognitive learning outcomes. It means that the 5E model can be useful for improving Slovak students' opinion on science and the choice of their future career, because they currently consider science difficult. Students also do not understand how science could be useful for their future career choices (Miklovičová et al., 2017).

However, it is necessary to point out that even though 5E model (in IBSE) has been used in teaching for a long time, teachers still face the following challenges: too many students in the classroom, lack of tools, laboratories, financial and material resources (age-and-grade-appropriate teaching and learning resources, access to electronic information resources, books, and computers) (Harlen, 2021). Further obstacles include the fact that teachers are worried about their own lack of knowledge and skills regarding IBSE and the 5E model implementation (Duncan et al., 2010; Fazio et al., 2010; Fogleman et al., 2011; Kim & Tan, 2011; Kong & Song, 2014; Levy et al. 2013; Melville et al., 2008; Roehrig & Luft, 2004). Some of these obstacles can only be removed by changes on the level of the whole education system, others can be overcome by individual schools or by providing teachers with further education or mentoring in the area.

CONCLUSIONS

The presented research investigated the effect of the 5E instructional model on the development of cognitive processes and students' attitudes towards chemistry as a subject.

The findings indicate that the teaching using the 5E model was more efficient than teaching without the 5E model. A statistically significant difference was identified. A detailed analysis of the chemistry concepts test indicated that the 5E model aided in the development of both the lower-order cognitive processes (memorization, understanding, and application) and the higher-order cognitive processes (analysis and evaluation).

The 5E model had a positive effect on students' attitudes to chemistry as a subject. The results showed a statistically significant improvement in post-application of the questionnaire as a whole in favor of the students who studied using the 5E model. The detailed analysis of the items indicated statistically significant differences in these students' attitudes in following dimensions: difficulty of chemistry, interest in chemistry, importance of chemistry for everyday life, importance of chemistry for future career.

These research findings indicate that using the 5E model as a teaching method can help Slovak students develop deeper understanding and positive attitudes toward science (chemistry), thus addressing the problems related to the lack of students' interest in the study of science and technology.

This problem could be solved by the new school reform, which is currently being implemented. The goals of this reform include modification of the educational contents and support for innovative teaching methods, digitalization of the education system, promoting inclusive education, and improving the quality of teacher education. teachers need. This suggests that teachers need long-term systematic professional development, which will contribute to a wider application of the 5E model in the teaching of several subjects.

Research Limits

1. **Objective limits:** Focus on a single thematic unit ("chemical reactions and equations") from the first-year grammar school students' chemistry book.
2. **Time limits:** The research was conducted in the second term of the 2021/2022 school year.
3. **Place limits:** The research was conducted in two Slovak cities (Prešov and Košice).
4. **Human limits:** The presented research was limited to a target group of first year students attending three grammar schools in Slovakia.
5. **Tools limits:** The research tools were limited to the application of the chemistry concepts test focused on the following cognitive levels: memorization, understanding, application, analysis, and evaluation. The questionnaire focused on students' attitudes towards chemistry as a subject investigated four dimensions: difficulty of chemistry, interest in chemistry, importance of chemistry for everyday life, importance of chemistry for future career.

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Ethical statement: Authors stated that the research study respected ethical principles. Beforehand, all participants (teachers and students) were informed of their role, the time schedule, and the fact that the research results would be published. All teachers and students consented to participate in this research. The teachers as well as legal representatives of the students involved signed the informed consent form. Authors further stated that for the purpose of statistical processing and evaluation of the data collected, each student was assigned a code to ensure protection of their personal data.

Declaration of interest: No conflict of interest is declared by authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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APPENDIX A: "CHEMICAL REACTIONS AND EQUATIONS" THEMATIC UNIT: DESCRIPTION OF INQUIRY ACTIVITIES

Table A1.

Inquiry activity
1. Exothermic and endothermic reactions
This activity demonstrates examples of exothermic and endothermic reactions. Students perform experiments to confirm the temperature changes in chemical reactions between vinegar and sodium bicarbonate, and sodium bicarbonate (solution) with calcium chloride (waterless). They write down these reactions using chemical equations of state. By experimenting with hot and cold packs (hand and feet warmers) and hot cans, students broaden their knowledge of exothermic and endothermic reactions.
2. The factors affecting the rate of chemical reactions
During this activity, students perform an experiment to confirm how different factors affect the rate of the chemical reaction between vinegar and sodium bicarbonate. First, they write down their assumptions about the factors that can affect the rate of this chemical reaction (vinegar concentration, temperature, amount, form of sodium bicarbonate–powder/tablets). Subsequently, they proceed to verify these factors in practice. Students observe the course of this reaction in a simple apparatus–a bottle with a balloon around its neck. These factors affect the speed with which the balloon is inflated by the carbon dioxide released. Students also observe the effect on catalysts on the rate of chemical reactions in an animation, which demonstrates how catalysts work in the car exhaust system. Finally, student draw conclusions and generalizations, which they apply to different situations.
3. The effect of temperature on the chemical equilibrium
This activity manifests how temperature affects the chemical equilibrium. Firstly, students review their knowledge of what a complex is and how a coordinate (donor-acceptor) bond is created. Then they watch a video showing how temperature affects the chemical equilibrium in the creation of colored cobalt complexes, specifically the cobalt tetrachloride complex $[CoCl_4]^{2-}$ and the hexa-aqua-cobalt complex $[Co(H_2O)_6]^{2+}$. Subsequently, students proceed to perform group experiments to confirm how temperature affects the chemical equilibrium between the solution and the solid Copper(II) nitrate (or potassium chloride). They draw conclusions from their own observation of the effect of temperature on the chemical equilibrium.
4. How carbon dioxide affects pH in solutions
The goal of this activity is to perform an experiment and confirm the acidogenic property of carbon dioxide (CO_2). During this experiment, students observe how CO_2 from the exhaled air or from natural mineral water affects pH. Moreover, they combine calcium carbonate with a diluted solution of hydrochloric acid to prepare CO_2 themselves. In the knowledge broadening phase, they learn about the causes and consequences of the increased CO_2 concentration in the atmosphere, e.g., ocean acidification.

APPENDIX B: "EXOTHERMIC AND ENDOTHERMIC REACTIONS" INQUIRY ACTIVITY (BASED ON 5E MODEL)

Table B1.

Engage

The students read a text about packs, which can instantly cool or heat (cold-and-hot packs). Subsequently, they answer questions applying their knowledge about exothermic and endothermic reactions.

Task 1: Read the text and answer the questions.

Cold and hot packs are activated by squeezing their inside. This triggers a chemical reaction that leads to cooling or heating the pack. Cold packs contain water and one of the following substances: ammonium nitrate, calcium nitrate, ammonium chloride, or urea. Hot packs contain water and one of the following substances: magnesium sulphate, calcium chloride.

Questions/tasks for students:

1. Explain the difference between exothermic and endothermic reactions.
2. What kind of reaction (exothermic or endothermic) takes place inside a cold/hot pack respectively?
3. Provide real-life examples how these packs could be used.

In this phase, teacher can examine students' knowledge & ideas to collect, record, & identify possible misconceptions.

Explore

Task 2: Imagine our task is to test single-use cold and hot packs. The packs contain a solution and a solid substance which, when reacted, produce the desired effect:

Pack 1 contains vinegar and sodium bicarbonate (powder), pack 2 contains a solution of sodium bicarbonate and calcium chloride (waterless).

Which effect occurs in the respective packs? Underline your assumption:

a) the pack 1 goes cold/hot.
b) the pack 2 goes cold/hot.

Subsequently, students verify their assumptions by performing an experiment.

Task 3: Perform an experiment according to instructions.

A glass or a digital thermometer can be used to measure the temperature.

Instruments: 2 beakers (250 ml), 2 measuring cylinders (50 ml), thermometer, 2 spoons, stirring rod

Chemicals: vinegar, sodium bicarbonate (powder), sodium bicarbonate (solution), calcium chloride (waterless)

During the experiment, the students observe two chemical reactions and record the temperature measurements in a table.

Reaction	t_1: Initial temperature [°C]	t_2: Final temperature [°C]	Δt [°C]	Exothermic/ endothermic reaction
Vinegar & sodium bicarbonate	22	15	-7	Endothermic
Sodium bicarbonate (solution) & calcium chloride (waterless)	22	27	+5	Exothermic

Note. When sodium bicarbonate (solution) reacts with calcium chloride (waterless), the temperature increase is not only due to reaction itself, but also to the dissolution of calcium chloride in water, which releases heat.

Explain

Teacher aims to compare students' results with their knowledge & possible misconceptions identified in previous phase.

Task 4: Answer the following questions.

1. What did you observe after sodium bicarbonate (powder) had been added to vinegar?
2. How did the temperature change when vinegar reacted with sodium bicarbonate?
3. What did you observe after calcium chloride (waterless) had been added to sodium bicarbonate solution?
4. How did the temperature change when the sodium bicarbonate solution reacted with calcium chloride?
5. Which gas was released during both reactions?
6. Were your assumptions from task 2 correct?

Task 5: Write the state equations of the chemical reactions observed and determine their stoichiometric coefficients.

$CH_3COOH(aq) + NaHCO_3(s) \rightarrow CH_3COONa(aq) + H_2O(l) + CO_2(g)$

$2NaHCO_3(aq) + CaCl_2\,(s) \rightarrow 2NaCl(aq) + CaCO_3(s) + H_2O(l) + CO_2(g)$

Elaborate

The teacher can deliver interesting information about (self-heating) Hot Cans. Alternately, students can be asked to find information about them on the Internet on their own. Hot cans are used to heat food using a reaction of water with magnesium oxide (in the presence of table salt). The products of this reaction are magnesium hydroxide and hydrogen. This reaction produces heat, and the water starts boiling. Its steam can heat up the food in about 10 minutes. The heating process starts by pulling on the handle of the can, releasing the water so that a chemical reaction can start. Hot cans are used for camping, hiking, or mountain climbing. Another example of exothermic reactions are hand and feet warmers.

Table B1 (Continued).

Evaluate
This phase can focus on students' self-assessment. Self-assessment cards allow students to analyze their own learning. Topic-related criteria are formulated on the card in advance. The students express their level of understanding on a scale (I need teacher's help, I don't understand yet ...).
Task 6: Check an option to express how much you agree with the above statements (see sample).
Demonstration of a self-assessment card filled by a student upon completion of the "exothermic and endothermic reactions" inquiry activity.

Student's name:	Form:		Date
Level of mastering subject matter	Independently	With teacher's assistance	I do not understand it yet
I can explain the difference between exothermic and endothermic reaction.		x	
I can provide examples of exothermic reactions.	x		
I can provide examples of endothermic reactions.		x	
I can perform experiment according to instructions.	x		

Upon evaluation, self-assessment cards show which knowledge students have and where assistance is still needed. A more frequent use of self-assessment cards in the evaluation phase motivates students to put in more effort and focus during next classes and inquiry activities.

APPENDIX C: CHEMISTRY CONCEPTS TEST

1. The chemical reactions during which heat is released are called ....
2. One of the reactants is missing in this chemical reaction of water autoproteolysis. Complete the formula.

$H_2O + \boxed{} \rightarrow H_3O^+ + OH^-$

3. By heating the reaction vessel from 30 °C to 50 °C, the rate of chemical reaction in this reaction vessel:
   a. Increases
   b. Decreases
   c. Remains unchanged
   d. Becomes null
4. The unit of mole binding energy is:
   a. kJ
   b. kJ.mol,
   c. $kJ.mol^{-1}$
   d. kJ/mol^{-1}
5. Determine which of the following reactions is exothermic based on the thermochemical equations:
   a. $1/2\ N_2(g) + 3/2\ H_2(g)$ ----------------> $NH_3(g) + 51.75$ kJ
   b. $1/2\ N_2(g) + 3/2\ H_2(g)$ ----------------> $NH_3(g)$; $\Delta H = 51.75$ kJ $\cdot mol^{-1}$
   c. $1/2\ N_2(g) + 3/2\ H_2(g)$ ----------------> $NH_3(g) - 51.75$ kJ
   d. $1/2\ N_2(g) + 3/2\ H_2(g) + 51.75$ kJ ----------------> $NH_3(g)$
6. Which of the following solutions has a pH greater than 7?
   a. Ammonia solution
   b. Sulphuric acid solution
   c. Lemon juice solution
   d. Vinegar solution
7. In everyday life, chemical processes take place all around us. During these processes, energy is released or used. Read the list below and indicate the process during which the total change in the internal energy of the reaction system is positive.
   a. Breathing
   b. Photosynthesis
   c. Burning
   d. Wood rotting
8. In a closed vessel, an endothermic reaction during which magnesium carbonate is decomposed is taking place. After some time, chemical equilibrium is stabilized. The reaction proceeds according to this equation:

   $MgCO_3$ (s) ----------------> MgO (s)+CO_2 (g)

   An increase in MgO product yield can be achieved:
   a. by adding CO_2 into the container.
   b. by crushing the $MgCO_3$ reactant.
   c. by adding more $MgCO_3$.
   d. by decreasing the temperature in the reaction vessel.
9. In the following chemical reaction scheme, the stoichiometric coefficients ***x, y, z, w*** are missing. Determine their values and write the sum of x + y + z + w.

   x $K_2Cr_2O_7$ + 6 KI + **y** HCl ---------> **z** $CrCl_3$ + **w** I_2 + 8 KCl + 7 H_2O

   $x + y + z + w =$ ....
10. Calculate the value of the equilibrium constant in the chemical reaction **A + B → 2C.** The relationship between the values of the equilibrium concentrations of all substances in this chemical reaction is as follows:

    2[A]= [B]=4[C];

    [A]= equilibrium concentration of substance A

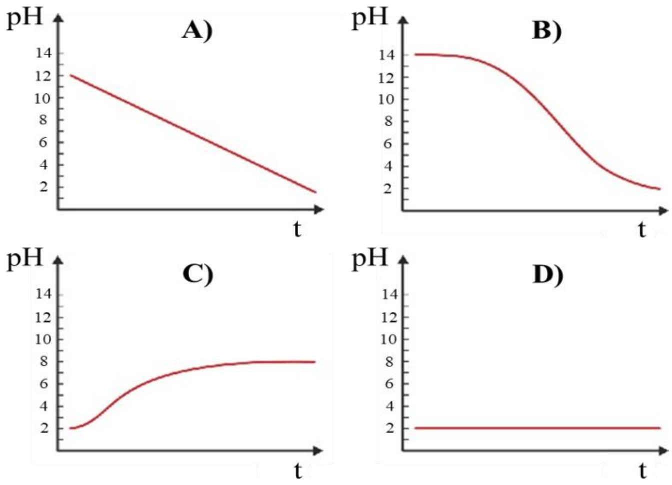
    [B]= equilibrium concentration of substance B

    [C]= equilibrium concentration of substance C

    Write the result as a decimal number without rounding.

    The value of the equilibrium constant of this chemical reaction is K = ...
11. In addition to digestive enzymes, the human stomach also contains hydrochloric acid at a concentration of approximately 0.01 mol×dm^{-3}, which is essential for the digestion of ingested food. However, excessive

stomach acid production can cause a burning sensation or pressure in your stomach and chest. This sensation is called **heartburn**. To relieve heartburn, we usually use antacids. Chemically, **antacids** contain alkaline compounds, e.g. magnesium hydroxide, aluminum hydroxide, or sodium bicarbonate. Determine which of these graphs (A-D) describes the process of antacid action in the stomach.



12. What can we see if we dip an iron nail into $AuCl_3$ solution?
    a. The iron nails starts dissolving in this solution.
    b. Chlorine in the form of bubbles is released from the solution.
    c. Black $FeAuCl_5$ precipitate forms on the bottom of the vessel.
    d. The separated gold can be seen on the nail.
13. Read the following list of chemical reaction equilibrium states. If we reduce the volume of the reaction system, in which of these states will the equilibrium shift towards the reactants?
    a. $H_2(g)+Cl_2(g) \leftrightarrow 2HCl(g)$
    b. $CO(g)+H_2O(g) \leftrightarrow CO_2(g)+H_2(g)$
    c. $NH_4Cl(g) \leftrightarrow NH_3(g)+HCl(g)$
    d. $HI(g) \leftrightarrow H_2(g)+I_2(g)$
14. Imagine you performed four chemical experiments and obtained the following results:
    1. You dropped a pellet of zinc and a pellet of copper, and an iron nail into the silver nitrate solution. White crystals of silver formed on the surface of all metals.
    2. You dropped per one pellet of copper, zinc, and silver, and an iron nail into dilute hydrochloric acid, but only the zinc pellet and iron nail reacted and released hydrogen bubbles.
    3. You dropped a pellet of zinc, a pellet of silver, and an iron nail into the copper sulphate solution. You observed how dark red copper coating formed on the surface of the zinc pellet and the iron nail.
    4. You dropped a pellet of zinc into the ferrous sulphate solution, and the zinc dissolved in the solution.

    Pick the option with the correct order of electrochemical series (or Becket series):

    a. Ag, Fe, Cu, Zn
    b. Fe, Cu, Zn, Ag
    c. Zn, Ag, Fe, Cu
    d. Zn, Fe, Cu, Ag
15. Pick the substance that <u>cannot</u> be used as a reducing agent in a chemical reaction.
    a. H_2S
    b. HNO_2
    c. HCl
    d. $HClO_4$