CHEMISTRY TEACHERS' OPINIONS ON AND ATTITUDES TO THE IMPLEMENTATION OF SYSTEMIC TASKS INTO TEACHING IN SLOVAKIA

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ABSTRACT

The goal of the research was to determine the opinions and attitudes of chemistry teachers regarding systemic tasks and their implementation into organic chemistry teaching at grammar schools. To achieve this goal, a set of work sheets with systemic tasks were created for the following topics in organic chemistry: Introduction to Organic Chemistry, Hydrocarbons, Hydrocarbon Derivates, Hydroxyderivatives and Carboxylic acids and their derivatives. This paper demonstrates examples of the systemic tasks that have been created to develop higher-order cognitive processes. 89 teachers used these tasks to teach 2136 second-year grammar school students over the course of two years (2019–2021). A questionnaire designed by the authors was used to collect the opinions of the teachers who participated in the presented research regarding the pros and cons of teaching using systemic tasks from the viewpoints of student motivation, deeper understanding of organic chemistry, students' ability to tackle such tasks, skill development, and time requirements. *[African Journal of Chemical Education—AJCE 13(4), December 2023]*

INTRODUCTION

Systemic Approach to Teaching and Learning (SATL) is a teaching strategy developed over the last two decades [1-7]. It aims to transform mechanical learning into learning with deep understanding [8]. This goal can be achieved through the development of systemic thinking by means of system-oriented learning tasks [9]. These tasks used closed schemes, also referred to as systemic diagrams, in which concepts are directly or indirectly linked to create a closed conceptual structure. Students are required to analyse, create, or complete a system diagram by employing systemic thinking to develop important skills such as the ability to distinguish concepts, identify relationships, analyse the system to identify basic components (concepts and links), and synthesize them into interconnected subsystems forming the whole [10]. Students do not learn isolated concepts by heart – they connect these concepts with facts in a logical context instead [11].

Many studies [12-16] dealing with science education emphasize the fact that systemic thinking is a particularly important higher-order cognitive skill, and it should be supported and developed during classes.

To address the requirement for improving students' creative and critical thinking in teaching, it is necessary to focus on developing the higher-order cognitive processes through suitable educational activities [17-18].

A number of studies [2, 10, 19-20] have addressed ideas for systemic tasks in organic chemistry and their implementation in teaching aimed at the development of systemic thinking skills in high school students. Their results confirm that teaching organic chemistry using systemic tasks really is more efficient than traditional teaching methods. According to [2, 19-20], SATL implementation significantly improved students' performance in high-school organic chemistry. These results also show that the SATL approach improved meaningful learning in organic chemistry, thus facilitating greater cognitive efficiency.

The affective surveys [2] indicate that students have a positive perception of the SATL approach. The studies published so far indicate that teachers' opinions on this teaching method have not yet been addressed.

The SATL approach is a new thing for chemistry teachers at Slovak schools, which is why the research presented in this paper aimed to identify their opinions on and attitudes to its implementation in the teaching of organic chemistry. To achieve this goal, worksheets with systemic tasks in organic chemistry focused on higher-order cognitive processes were created. Chemistry teachers implemented them in teaching grammar school chemistry and subsequently took a survey allowing the research team to identify their opinions on and attitudes to these tools.

Research Problem

Slovakia is one of the countries where teacher-centered methods still prevail [21-22].

In the long term, it reflects in the OECD PISA results (Programme 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 [23]. Slovak students find it difficult to deal with tasks that require higher-order cognitive processes such as analysis, evaluation, and creativity [24]. As indicated by [3], systemic tasks have the potential to develop and verify higher-order cognitive processes such as analysis, synthesis, and evaluation as specified in Bloom's taxonomy [25-26].

Therefore, inclusion of systemic tasks into teaching organic chemistry at grammar schools can be considered a suitable way to shift from memorisation to meaningful learning with deep understanding. However, teachers must take the first step, become familiar with these types of tasks and learn how to use them in teaching.

Research Aim and Research Questions

The goal of this research was to identify the opinions and attitudes of chemistry teachers regarding systemic tasks and their implementation into organic chemistry teaching at grammar schools.

This research addressed the following research questions:

1. To what extent do the systemic task worksheets comply with the content and performance standards of Chemistry as an academic subject according to the State Educational Programme (SEP) for grammar schools?
2. What are the pros of the implementation of systemic tasks into teaching?
3. Which skills of the students are developed by systemic tasks?
4. What are the cons of implementation of systemic tasks into teaching?

METHODOLOGY

Research Design

In this research the questionnaire design was employed. Questionnaires are widely used in educational research [27-29]. [30] explained that their popularity may be explained by the benefits they have for gathering qualitative research data compared to other qualitative methods, such as interviews or focus groups (convenience, cost, standardization, 'self-administered', validity, reliability, anonymity, and 'scalability'). The questions used within a questionnaire should provide answers to research questions. Attitudinal questions aim to find and explore respondent's attitudes or beliefs about a particular subject [31-32]. This type of questions aims to identify respondent's attitude to the subject matter. Closed questions are typically used when the respondent can provide a specific answer or when there are many ways to answer a question, and the researcher has a pre-defined set of answers [33]. Figure 1 presents the phases of this research.

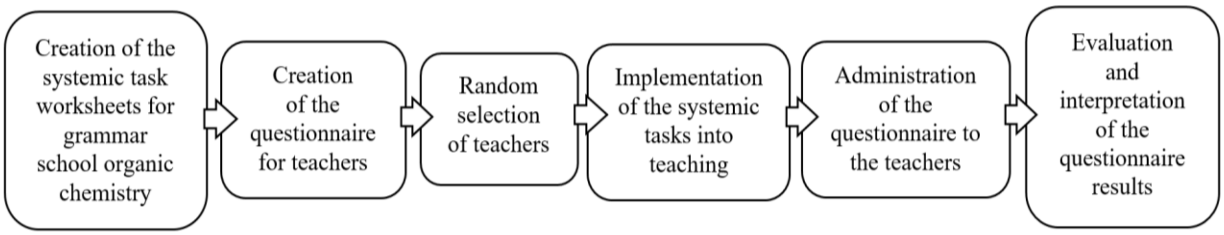


Figure 1: Phases of the research.

Preparation of Experimental Processing Tools and Measurements

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

1. Choosing the educational content

In Slovakia, organic chemistry as a subject matter is taught mostly in the 2nd year of 4-year grammar schools or 6th year of 8-year grammar schools. The State Educational Programme for grammar schools [34], part ‘Chemistry as an academic subject’, points out that it is important to emphasize the context, i.e., students are supposed to understand how the structure of organic substances is linked to their properties as well as reactivity principles and the most important reactions. Reactivity of organic compounds is one of the most difficult parts of organic chemistry study.

2. Preparation of systemic task worksheets for organic chemistry

In accordance with the content and performance standards of Chemistry as an academic subject for grammar schools [34], a set of work sheets with systemic tasks were created for the following topics in organic chemistry: Introduction to Organic Chemistry, Hydrocarbons, Hydrocarbon Derivates, Hydroxyderivatives and Carboxylic acids and their derivatives. This worksheet contained systemic tasks focused on the following subject matters: types of chemical reactions and organic compounds, relationships between hydrocarbons and their derivatives, hydroxyderivatives of hydrocarbons and their reactivity, carboxylic acids, and their derivatives with emphasis on reaction conditions/reagents. The systemic tasks created by the research team enhance students' ability to work with specialised texts and schemes, analyse information, and synthesize them. They also help develop students' ability to work in pairs or groups, discuss, communicate, and provide arguments.

From the viewpoint of cognitive processes according to revised Bloom's taxonomy (hereinafter RBT) [26], systemic tasks in these worksheets are focused on higher-order cognitive operations such as:

- the ability to apply knowledge in new, specific situations,
- the ability to analyse or synthesize individual parts of a system diagram,
- the ability to compare and evaluate whether the system diagrams provided are correct.

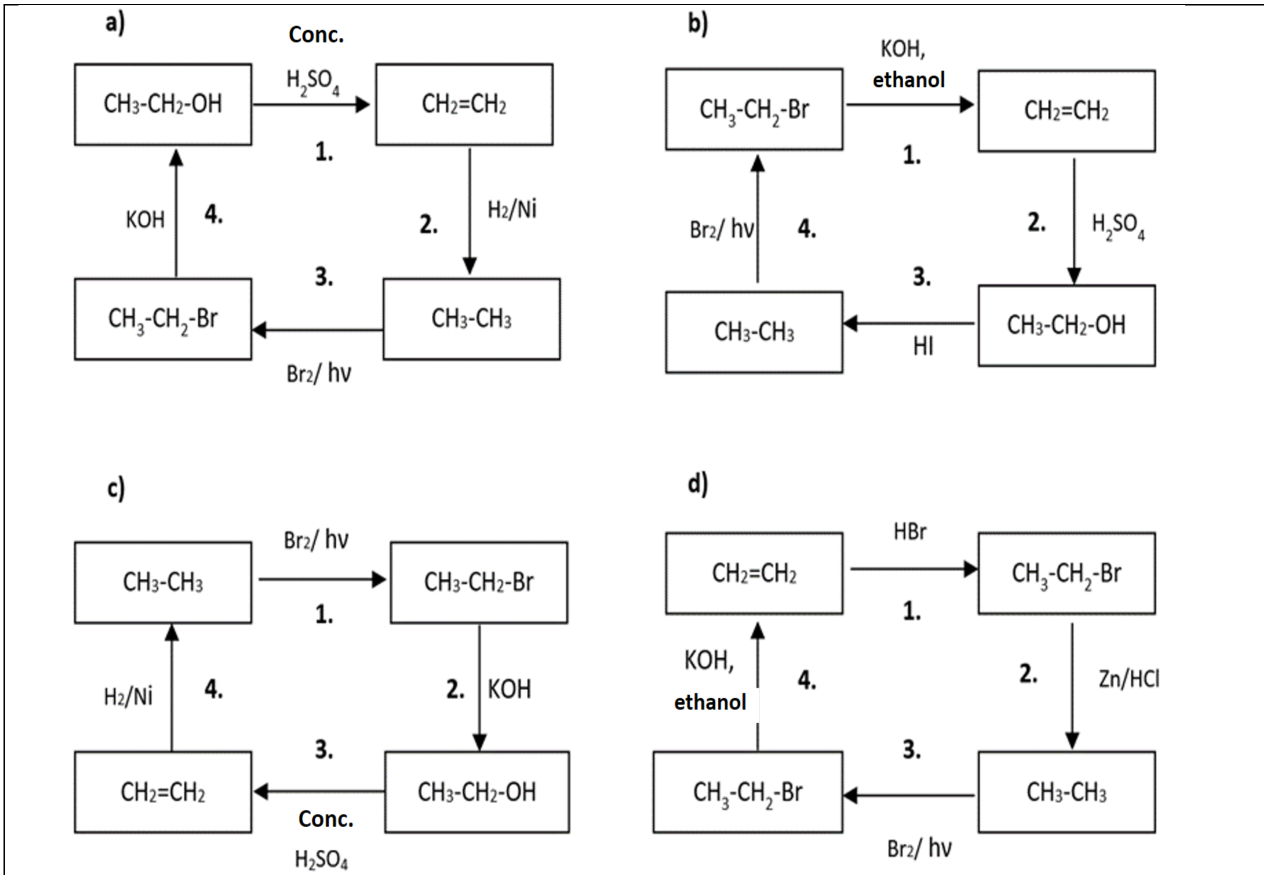
However, it is necessary to point out that the diagrams in the systemic tasks only contain schematic (incomplete) equations, therefore by-products are sometimes not supposed to be written down.

All worksheets were created in cooperation with teachers, pilot-tested, and optimised. In the creation of the systemic tasks, the authors drew on relevant publications [6, 9, 11]. Some tasks have already been published in previous research papers; others were created from scratch in cooperation with teachers.

Table 1 shows examples of systemic tasks focused on higher-order cognitive processes used in the worksheets created for organic chemistry.

Table 1: Examples of systemic tasks in organic chemistry assigned to the respective dimensions of knowledge and cognitive processes according to RBT.

Task 1 – Systemic True False **Dimension of knowledge/cognitive process:** conceptual knowledge/analysis Determine which system diagram shows the course of chemical reactions in this order: substitution – substitution – elimination – addition.



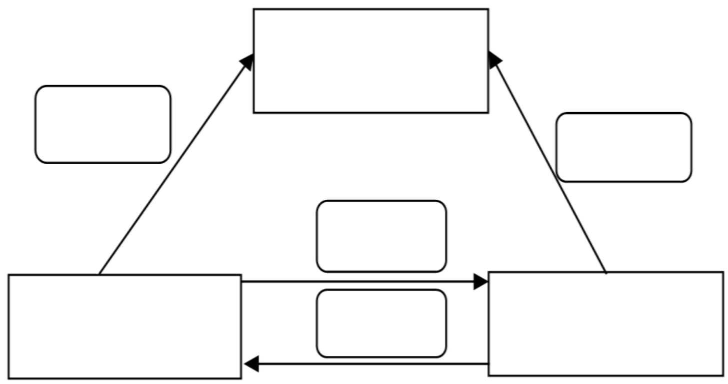
Students are supposed to analyse all answers and pick the correct one. This task can be expanded by asking the students to explain their reasoning.

Solution: Systemic diagram c) is correct.

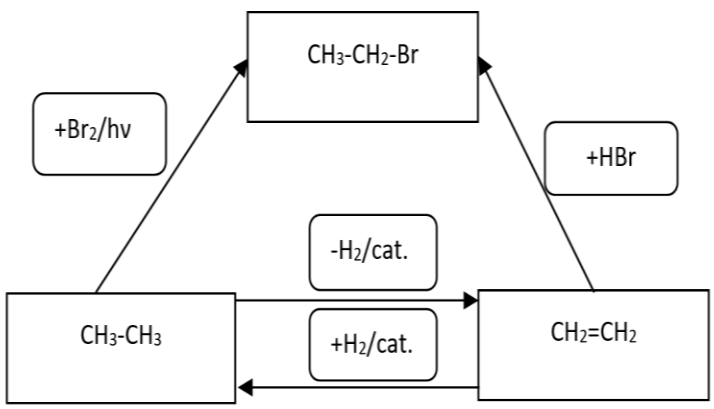
Task 2 – Systemic Matching

Dimension of knowledge/cognitive process: conceptual knowledge/analysis

Link compounds in column A to reaction conditions/reagents in column B and note down the system diagram into column C.

A	C	B
$CH_2=CH_2$ CH_3-CH_3 CH_3-CH_2-Br		$+Br_2/hv$ $+HBr$ $-H_2/cat.$ $+H_2/cat.$

Solution:

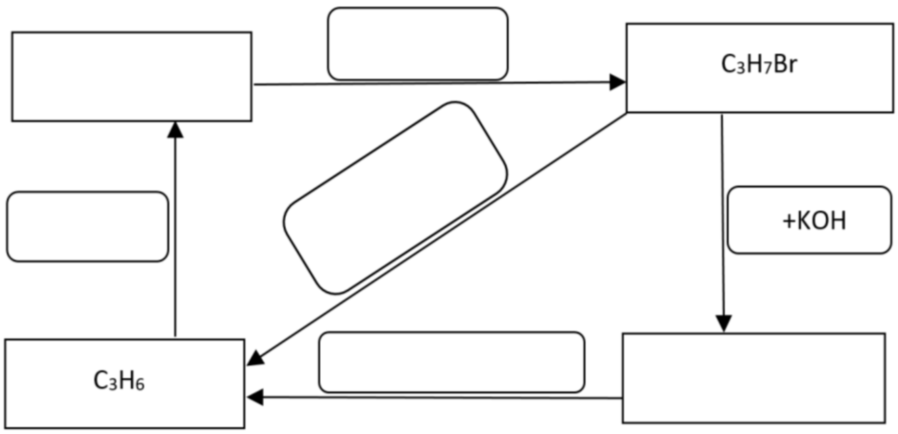
A	C	B
$CH_2=CH_2$ CH_3-CH_3 CH_3-CH_2-Br		$+Br_2/hv$ $+HBr$ $-H_2/cat.$ $+H_2/cat.$

This task can also be used for assessment, points can be assigned for correct links between the compounds and reaction conditions/reagents in the diagram.

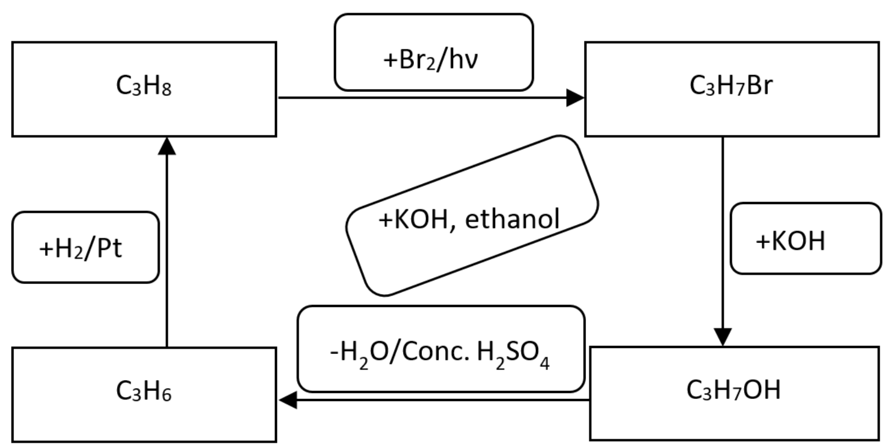
Task 3 – Systemic Sequencing, Completion

Dimension of knowledge/cognitive process: procedural knowledge/analysis

Categorise the organic compounds C_3H_8 and C_3H_7OH and proceed to fill in the reaction conditions/reagents into the system diagram below.



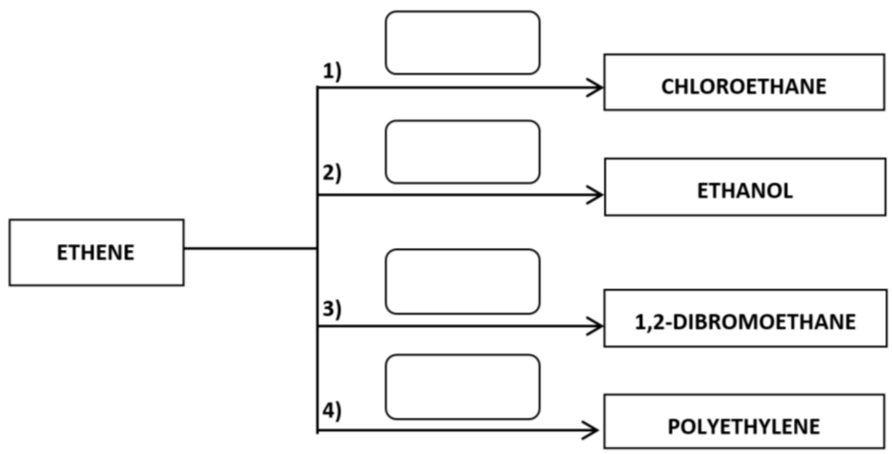
Solution:



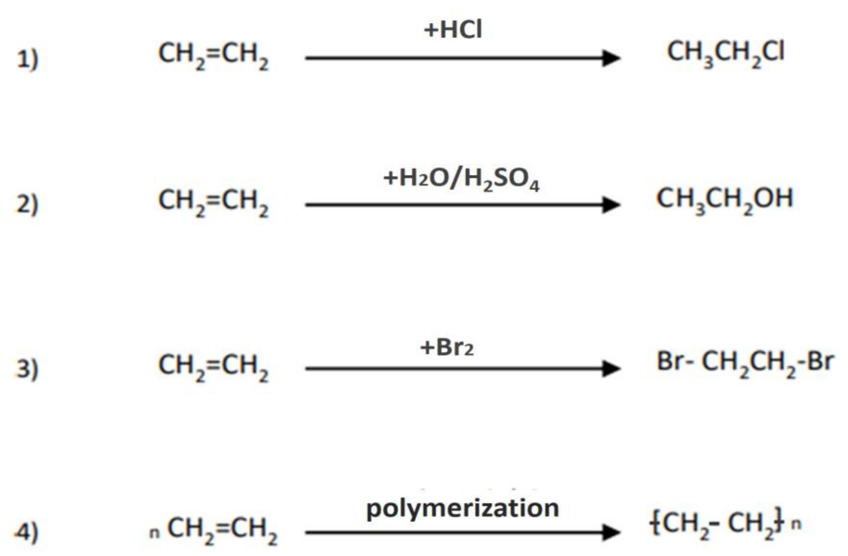
Task 4 – Systemic Synthetic-Analytic

Dimension of knowledge/cognitive process: procedural knowledge/analysis

Fill in the correct reaction conditions/reagents into the diagram and write down the respective reactions using chemical equations. Name the reaction No. 4.



Solution:



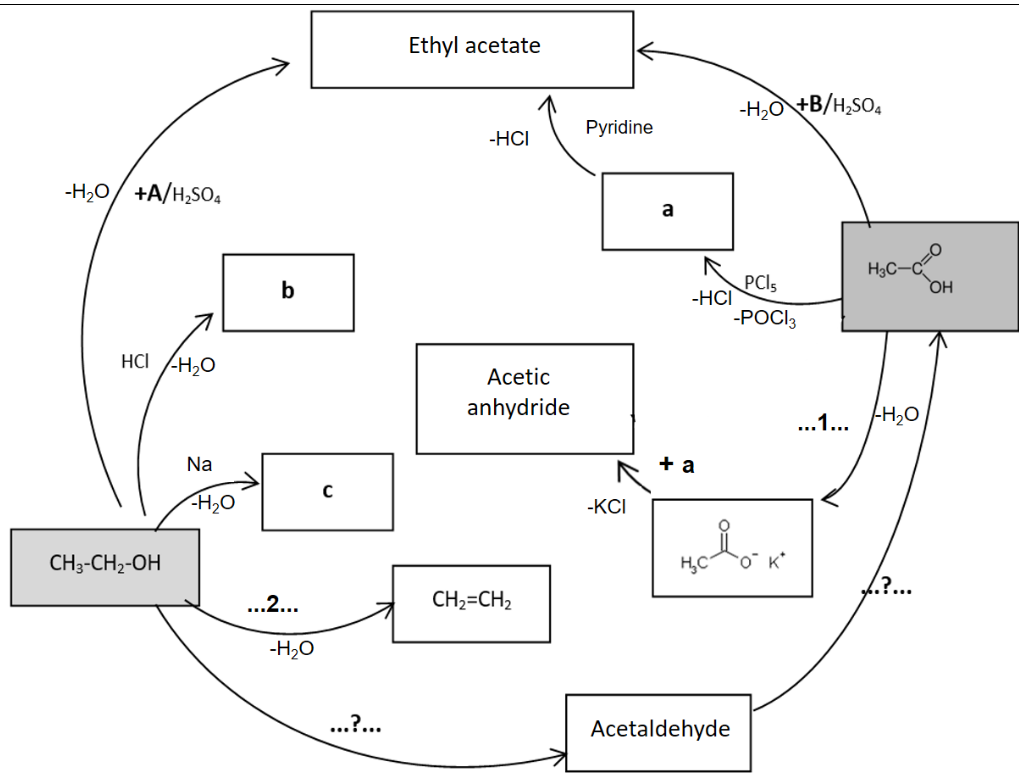
Worksheets contained more difficult tasks consisting of multiple types of systemic tasks as well. For example, the systemic task for the topic Carboxylic Acids and Their Derivatives contained partial tasks focused on completion, analysis, and synthesis. This task is suitable for group work.

Task 5 – Completion, Systemic Synthetic-Analytic

Dimension of knowledge/cognitive process: procedural knowledge/analysis, evaluation

The diagram below shows reaction relationships between hydrocarbons, hydrocarbon derivatives, carboxylic acids, and their derivatives. Fill in:

A. names of the products (a–c)
B. reaction conditions (1–2)
C. names of the reactants (A–B)
D. type of the reaction (?)



Solution:

a – Acetyl chloride, b – Ethyl chloride/Chloroethane, c – Sodium ethoxide (Sodium ethanolate)

1 – KOH, 2 – Conc. H_2SO_4, heat

A – *Acetic acid*, B – Ethanol

? – Oxidation

Tasks focused on the development of metacognitive skills

Worksheets end with tasks focused on the development of students' metacognitive skills. The experience indicates that it is often difficult for students to evaluate their own performance verbally. However, a self-assessment card as a formative assessment tool allows them to evaluate their own understanding of the subject matter. It provides the criteria that help students subjectively describe their level of knowledge and skills, which they intuitively feel, but are unable to express verbally [35].

Students' answers in the self-assessment cards show which knowledge students have and where assistance is still needed with systemic tasks, thus providing both the teacher and students with feedback. Based on this feedback, the teacher can adjust and plan further implementation of systemic tasks in teaching.

Below are examples of self-assessment cards for the topics Hydrocarbons (Table 2) and Carboxylic Acids (Table 3) filled by students.

Table 2: An example of a self-assessment card for the topic Hydrocarbons filled by a student (with excellent academic record).

Put in a cross to indicate how much you agree with the respective statement	**Yes without assistance**	**Partially, with assistance**	**Not yet**
I can complete system diagrams using formulas and reaction conditions/reagents, which correctly express the reactions between alkanes, alkenes, and alkynes.	x		
I can use system diagrams to **write down** chemical equations expressing the reactions between alkanes, alkenes, and alkynes.	x		
I can create a system diagram based on the organic substances/compounds and reaction conditions/reagents provided.		x	

Table 3: An example of a self-assessment card for the topic Carboxylic Acids filled by a student (with average academic record).

Put in a cross to indicate how much you agree with the respective statement	**On my own**	**With some assistance**	**With major assistance**
I can write down the formulas of important carboxylic acids.	x		
I can add reaction conditions/reagents for the reactions during the preparation of carboxylic acids.	x		
I can write down the products of carboxylic acid reactions and name them.		x	
I can analyse the system diagram of chemical reactions between alcohols and carboxylic acids, add the reaction conditions, products, and type of reaction.			x
I can provide arguments and justify the correctness of my claims.			x

Self-assessment cards allow students to track their own learning processes, evaluate their efficiency, and if necessary, modify the learning strategies.

Research Tool

Teachers' opinions on and attitudes to systemic tasks in the worksheets after teaching organic chemistry with them were collected via an electronic feedback questionnaire developed by the authors. The questionnaire consisted of two modules. Module A focused on the basic information about the respondents/teachers. Module B included 14 items divided into three areas in line with the research questions. Teachers expressed their opinions on and attitudes to individual questionnaire items using a three-point scale ("yes," "I do not know", "no"). The questionnaire can be comfortably completed in 25 minutes.

To ensure that the questionnaire items were valid, it was analysed by an associate professor at the Department of Chemistry Education to verify that the items were relevant to the objectives of the research. The reliability of the questionnaire was calculated using the Cronbach's alpha [36]; $\alpha=0.783$ is an acceptable reliability coefficient.

Research Sample

The research sample consisted of 89 grammar school chemistry teachers and data were collected over two academic years (2019–2021). The grammar schools were selected randomly and covered the whole country. All teachers involved in this research participated in the IT Academy –

Education for the 21st Century project (2016–2021, https://itakademia.sk/) and expressed their interest in implementing the systemic task worksheets developed by the authors in teaching. A total of 2136 second-year grammar school students participated in the research. During the COVID-19 pandemic, approx. 50% teachers used the worksheets for online teaching (mostly via MS Teams).

Ethical Consideration

All teachers were informed about the objectives of the research, and their participation was voluntary and anonymous. Online consent with the participation in this research was obtained from the teachers.

Data Analysis

The questionnaires were administered online, collected, and analysed using the Statistical Package for Social Science (SPSS) version 18 [37]. Basic data evaluation was performed. The items were analyzed according to the questionnaire areas as well as separately.

RESULTS

In this part of the paper, the results of the questionnaire focused on teachers' opinions on and attitudes to the implementation of systemic tasks in teaching will be presented (Tables 4–6).

1. **To what extent do the systemic task worksheets comply with the content and performance standards of Chemistry as an academic subject according to the State Educational Program for grammar schools?**

Table 4: Teachers' opinions on and attitudes to systemic tasks in the worksheets.

Teacher responses [%]	**Yes**	**I do not know**	**No**
1) Systemic tasks enhance and consolidate students' knowledge in accordance with the goals specified in the SEP for grammar schools.	87.64	12.36	0.00
2) Systemic tasks have been created professionally, are clear, and comprehensible.	89.89	10.11	0.00
3) The order of the systemic tasks in the worksheets is consistent with their increasing difficulty.	88.76	11.24	0.00
4) The systemic tasks are variable (completion, matching, synthesis, analysis, synthetic-analytic, sequencing, true-false).	88.76	11.24	0.00

Note: No negative response was recorded on the three-point scale.

2. **What are the pros of the implementation of systemic tasks into teaching and which skills do they develop in students?**

Table 5: Chemistry teachers' opinions on and attitudes to the implementation of systemic tasks into teaching – pros.

Teacher responses [%]	**Yes**	**I do not know**	**No**

5) Systemic tasks connect the existing knowledge to the new one, which helps students understand the context, i.e., consolidation and learning with deep understanding is achieved.	89.89	10.11	0.00
6) Unlike traditional tasks, systemic tasks develop higher-order cognitive processes such as analysis or evaluation (according to RBT).	84.27	15.73	0.00
7) Systemic tasks allow for the identification of students' misconceptions.	82.02	17.98	0.00
8) Systemic tasks develop the following skills:			
- critical thinking	88.76	11.24	0.00
- argumentation	88.76	11.24	0.00
- group cooperation	84.27	15.73	0.00
- the ability to create, analyse, and complete system diagrams	89.89	10.11	0.00
- result interpretation	82.02	17.98	0.00
- drawing conclusions and generalisations.	86.51	13.49	0.00
9) Students are interested in doing systemic tasks.	78.65	13.48	7.87
10) I plan to continue using these types of tasks in teaching.	88.76	11.24	0.00

3. What are the cons of the implementation of systemic tasks into teaching?

Table 6: Chemistry teachers' opinions on and attitudes to the implementation of systemic tasks into teaching – cons.

Teacher responses [%]	Yes	I do not know	No
11) Time requirements – lack of time to complete systemic tasks (mainly during distance teaching).	40.44	10.11	49.45
12) Lack of methodological material for more topics.	73.03	11.24	15.73
13) Insufficient skills to implement systemic tasks into teaching.	41.57	11.24	47.19
14) Students have insufficient theoretical knowledge to deal with systemic tasks.	60.67	10.11	29.22

DISCUSSION

In this research, the evaluation of teachers' opinions on the positive and problematic aspects of the systemic tasks implementation into teaching were presented.

According to 87.64% of teachers, the systemic task worksheets provided enhance and consolidate students' knowledge in accordance with the goals specified in the Chemistry SEP for grammar schools [34].

88.76% of teachers perceived the increasing difficulty of systemic tasks in the worksheets as positive as it encouraged students to go on. If they correctly completed the initial simpler tasks, they were more motivated to consider the more difficult ones, which is in line with RBT goals [26].

Systemic tasks connect the existing knowledge to the new one, which helps students understand the context, consolidate their knowledge, and learn with deep understanding (according to 89.89% teachers). Similarly, [2, 6, 38-39] opined that SATL-based learning is an active process where learners are encouraged to discover principles, concepts, and facts, and arrange them in a systemic relationship. SATL increases students' ability to learn the subject matter in a broader context.

The systemic task worksheets help students develop higher-order cognitive processes such as analysis, synthesis, and evaluation (according to 84.27% of the teachers). Systemics emphasizes the development of higher-order cognitive skills [6, 40] as defined by Bloom [25-26]. Abilities such as formulating questions and arguments, drawing conclusions, critical and systemic thinking also pertain to the higher-order cognitive skills [41-43]. Most teachers evaluated the development of these skills via systemic tasks positively (Table 5). SATL allows for important educational interactions among students or students – teacher [6], which facilitates the development of communication skills (according to 84.27% teachers).

Dealing with systemic tasks helps students develop science literacy [44-45]. 82.02% teachers believe that systemic tasks allow for the identification of students' misconceptions stemming from incorrect understanding of the previous educational content, which influences their ability to comprehend the basics of organic chemistry. Therefore, the construction of mental models is an important goal of learning and teaching organic chemistry. In this case, the risk that the student will inadvertently remember incorrect answers from single-choice test questions is removed [46].

It must be pointed out that students involved in this research lacked previous knowledge about e.g., nomenclature of the organic compounds, determining the types of chemical reactions or reaction conditions/reagents, which affected their ability to complete the tasks. The available research [47-48] has also identified certain problems with the ability to complete the systemic tasks due to insufficient understanding of the relationship between the structure and properties of organic compounds.

Concerning the cons of using systemic tasks in teaching, teachers mostly complained about the time requirements, the lack of worksheets for other topics, and the necessity to receive training beforehand (Table 6).

Slovak experience is consistent with other countries in which teachers always complain about the lack of time when it comes to the implementation of teaching methods focused on active student work [49].

The traditional way of teaching focused on explaining the subject matter is less time-consuming, but the knowledge developed by students is often superficial and without deep understanding. On the other hand, active learning can help students discover new ways to tackle complex concepts and problems. It promotes creativity and develops problem-solving skills, which will be highly useful to students in their future life and careers [50-51].

Even teachers with differing experience, expertise, and age can be trained to use SATL in a short time. Although the teacher training programme requires activities focused on creating SATL materials [10], the SATL methods can be used by any teacher who undergoes the training and receives materials.

CONCLUSION

The presented research showed that the systemic tasks designed by the authors are fully implementable in teaching organic chemistry in the 2nd year of 4-year grammar schools or 6th year of 8-year grammar schools. They can also be used for revision during the seminars taken in the final year. Teachers do not need extensive training.

Teachers implemented the systemic tasks into teaching with the aim to motivate students and provide them with feedback to improve their learning process. Therefore, systemic tasks can also be considered a type of formative assessment. Some teachers used the systemic tasks for the purpose of summative assessment, i.e., they assigned points and calculated grades.

Systemic tasks require students to create, analyse, and complete system diagrams, which helps them develop higher-order cognitive processes such as analysis, synthesis, and evaluation, which in turns, promotes deep understanding.

Completing systemic tasks develops critical and systemic thinking as well as skills such as the ability to formulate questions and arguments or draw conclusions – which memorisation does not.

Systemic tasks help identify the reasons why students are unable to complete them by identifying their misconceptions stemming from the incorrect understanding of the previous educational content.

It is also efficient to use self-assessment cards after the completion of systemic tasks to let students analyse the correctness of their answers.

Both teachers and students want to continue working with systemic tasks in more topics (e.g., biochemistry) and even other academic subjects.

Teachers also recommend short training using the existing materials and systemic tasks before using them in teaching or creating them.

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