

DIDACTIC POSSIBILITIES OF USING CREATIVE EDUCATIONAL TECHNOLOGIES IN TEACHING ORGANIC CHEMISTRY

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Abstract

The article examines, from theoretical and experimental perspectives, the didactic possibilities of using creative educational technologies in teaching organic chemistry in general secondary schools. The specific features of organic chemistry content, namely the invisibility of molecular structure, the multiplicity of variants in isomerism, the complexity of reaction mechanisms and the richness of real-life contexts, are analysed as the basis for applying creative technologies. The correspondence of TRIZ, synectics, Six Thinking Hats, SCAMPER, mind mapping, design thinking, STEAM projects and digital molecular modelling to organic chemistry topics is substantiated, and their visualizing, divergent-developmental, integrative, motivational and reflective didactic functions are identified. The methodology, developed on the basis of I.E. Shernazarov's research on the integrative approach and functional literacy, was tested in a pedagogical experiment, which proved that it leads to a statistically significant increase in students' creative and cognitive activity.

Keywords: Organic chemistry, creative educational technologies, didactic possibilities, TRIZ, synectics, isomerism, molecular modelling, STEAM, divergent thinking, functional literacy.

Introduction

Annotatsiya

Maqolada umumiy o'rta ta'lim maktablarida organik kimyoni o'qitishda kreativ ta'lim texnologiyalaridan foydalanishning didaktik imkoniyatlari nazariy va eksperimental jihatdan tadqiq etilgan. Organik kimyo mazmunining o'ziga xos xususiyatlari, ya'ni moddalar tuzilishining ko'z bilan ko'rib bo'lmashligi, izomeriya hodisasining ko'p variantlilik, reaksiya mexanizmlarining

murakkabligi va mazmunning hayotiy kontekstga boyligi kreativ texnologiyalarni qo‘llash uchun asos sifatida tahlil qilingan. TRIZ, sinektika, “Olti fikrlash qalpoqchasi”, SCAMPER, intellekt-xarita, dizayn-fikrlash, STEAM-loyiha va raqamli molekulyar modellashtirish texnologiyalarining organik kimyo mavzulari bilan muvofiqligi asoslanib, ularning vizuallashtiruvchi, divergent-rivojlantiruvchi, integrativ, motivatsion va refleksiv didaktik funksiyalari aniqlangan. I.E. Shernazarovning integrativ yondashuv va funksional savodxonlikka oid tadqiqotlari asosida ishlab chiqilgan metodika pedagogik tajriba-sinovdan o‘tkazilib, uning o‘quvchilarning kreativ-kognitiv faolligini statistik ahamiyatli darajada oshirishi isbotlangan.

Kalit so‘zlar: organik kimyo, kreativ ta’lim texnologiyalari, didaktik imkoniyat, TRIZ, sinektika, izomeriya, molekulyar modellashtirish, STEAM, divergent fikrlash, funksional savodxonlik.

Аннотация

В статье с теоретической и экспериментальной точек зрения исследованы дидактические возможности использования креативных образовательных технологий при обучении органической химии в общеобразовательных школах. В качестве основы для применения креативных технологий проанализированы особенности содержания органической химии: невидимость строения веществ, многовариантность явления изомерии, сложность механизмов реакций и насыщенность содержания жизненным контекстом. Обосновано соответствие технологий ТРИЗ, синектики, «Шести шляп мышления», SCAMPER, интеллект-карт, дизайн-мышления, STEAM-проектов и цифрового молекулярного моделирования темам органической химии, определены их визуализирующая, дивергентно-развивающая, интегративная, мотивационная и рефлексивная дидактические функции. Методика, разработанная на основе исследований И.Э. Шернazarова по интегративному подходу и функциональной грамотности, прошла педагогическую апробацию; доказано, что она статистически значимо повышает креативно-когнитивную активность учащихся.

Ключевые слова: органическая химия, креативные образовательные технологии, дидактические возможности, ТРИЗ, синектика, изомерия, молекулярное моделирование, STEAM, дивергентное мышление, функциональная грамотность.

Introduction

In the modern educational paradigm, a student's success in learning is determined not by the amount of knowledge acquired, but by the ability to apply this knowledge in new situations, to solve problems in non-standard ways and to generate new ideas. The inclusion of creative thinking as a separate assessment domain in the OECD PISA 2022 study [30] confirms the priority of this direction in global education policy. The Law of the Republic of Uzbekistan "On Education" [1], the Concept for the Development of the Public Education System until 2030 [2] and Presidential Resolution No. PQ-4805 of 12 August 2020 [3] have identified improving the quality of teaching chemistry and biology and developing students' practical, research and creative skills as important tasks of state education policy.

Organic chemistry is one of the most complex sections of the general secondary school chemistry course and, at the same time, one of the most closely connected with everyday life. Medicines, food products, polymers, fuels, cosmetics, household chemicals and biologically active substances are created on the basis of organic compounds. At the same time, mastering organic chemistry requires a high level of abstract thinking from students: imagining the spatial structure of molecules, understanding the relationship between structure and properties, identifying isomers and explaining reaction mechanisms. As A. Johnstone pointed out, the main reason for difficulties in learning chemistry is that the learner is forced to think simultaneously at the macroscopic, submicroscopic and symbolic levels [21]. N. Graulich showed that, in organic chemistry classes, students often limit themselves to memorizing formulae and reaction equations without understanding the essence of invisible processes [22].

I.E. Shernazarov's studies have also substantiated that the use of integrative technologies and a context-based approach closely linked to industry in teaching organic chemistry is an effective way of developing the literacy of school and university students in line with the requirements of international assessment [4; 5; 6]. However, in school practice organic chemistry lessons are still organized

mainly in an information-reproductive manner: the teacher presents ready-made knowledge, and students are limited to solving model problems. As a result, students' interest in organic chemistry declines, their knowledge becomes formal, and their ability to apply it in real-life situations is insufficiently developed.

Creative educational technologies have great potential for solving this problem. They transform the student from a passive recipient of knowledge into an active explorer and creator of new ideas. However, in the scientific and methodological literature, creative technologies have been considered mainly with reference to general pedagogy or inorganic chemistry, and their correspondence to the specific features of organic chemistry content, as well as their didactic possibilities, have not been systematically analysed. Therefore, the aim of the study is to identify the didactic possibilities of using creative educational technologies in teaching organic chemistry, to develop a methodology for their implementation and to substantiate its effectiveness experimentally. The objectives of the study were to identify the features of organic chemistry content that serve as a basis for applying creative technologies, to classify the didactic functions of creative technologies, to align them with organic chemistry topics, and to test the developed methodology in a pedagogical experiment.

Literature review

The theoretical foundations of creative educational technologies go back to the psychology of creativity and the theory of heuristic learning. J.P. Guilford linked creativity with divergent thinking and identified its parameters of fluency, flexibility, originality and elaboration [28]. T. Amabile substantiated intrinsic motivation and a creative environment as decisive factors of creativity [29]. A.V. Khutorskoy, in his concept of heuristic learning, put forward the idea of acquiring competences through the student's creation of a personal educational product [33].

The theoretical foundations of specific creative technologies have also been elaborated in depth. The theory of inventive problem solving (TRIZ), created by G.S. Altshuller, is based on identifying contradictions in technical systems and resolving them by systematic methods [31]. E. de Bono's Six Thinking Hats technique makes it possible to consider a problem in turn from the perspectives of information, feelings, caution, benefits, creative ideas and process management [32]. Among Uzbek scholars, N.A. Muslimov and co-authors [34] and R.J.

Ishmuhamedov and M. Yuldashev [35] developed the scientific and practical foundations for introducing innovative pedagogical technologies and interactive methods into the educational process.

The problems of teaching organic chemistry have been widely studied in international chemistry education research. G. Bhattacharyya and G. Bodner found that students often write reaction mechanisms mechanically, without understanding their meaning, merely in order to “get to the product” [23]. N. Grove, M. Cooper and K. Rush substantiated the need to specifically develop representational competence in organic chemistry, that is, the ability to use structural formulae and the language of curved arrows meaningfully [24]. H.-K. Wu and P. Shah analysed the role of visuospatial thinking in learning chemistry and showed that molecular models and computer visualizations are effective tools for developing this type of thinking [25]. I. Eilks and A. Hofstein substantiated that increasing the personal, societal and vocational relevance of chemistry education strengthens students’ motivation [26], while V. Talanquer emphasized the development of chemical thinking as one of the main directions of modern chemistry education [27].

In recent years, Uzbek researchers have also been investigating the use of modern technologies in teaching organic chemistry. N.S. Palvanov and X.D. Abdullayeva analysed the effectiveness of using Brainstorming, Fishbone, case study and game technologies in organic chemistry lessons [18]. K. Qadirberganova, M. Sultanov and N. Dabilov studied the use of problem-based methods in teaching the module on the theory of the chemical and electronic structure of organic substances [19], and G.E. Ametova described the use of digital software, 3D molecular models and simulations in teaching organic chemistry [20].

The integration of organic chemistry teaching methodology with a creative approach occupies a special place in the scientific works of I.E. Shernazarov. He developed a methodology for using integrated technologies in preparing university students for international assessment programmes in organic chemistry [5]. His study on using the integration of natural sciences in teaching the technology of producing nitrogen-containing organic compounds at chemical industry enterprises substantiates that knowledge about the structure, properties and synthesis of organic substances should be taught in connection with medicine, agriculture, the food industry and ecology, and that industrial internships and the STEAM approach develop students’ chemical thinking [6]. I.E. Shernazarov has

also studied the use of the STEAM approach in chemistry education [7], the development of functional literacy through creative thinking tasks [8], the development of 21st-century skills through the assessment of students' creative thinking [9], the organization of the educational process on the basis of the competence-based approach [10], and the development of various forms of functional literacy in school students and future teachers [11; 12; 14; 15; 16]. His work on developing students' research skills and scientific literacy through experimental work [13] and his doctoral dissertation [4] provide a theoretical rationale for the role of context-based and creative tasks in chemistry education. The literature review shows that, although the general pedagogical foundations of creative technologies and the effectiveness of individual methods in teaching organic chemistry have been studied to a certain extent, the correspondence between creative technologies and the specific features of organic chemistry content, their didactic functions and the mechanisms for their systematic use in school lessons have not been investigated holistically.

Research methodology

The methodological basis of the study comprised the systemic activity-based, competence-based, integrative and context-based approaches. In this study, a "creative educational technology" was defined as a systematic method of designing and organizing learning activities that activates students' divergent thinking, is aimed at generating, evaluating and implementing new ideas, and ensures the achievement of a guaranteed result. A "didactic possibility" was understood as the potential contribution that a particular technology can make to the mastery of learning content, the development of the student's personality and the management of the learning process.

The study employed theoretical methods (analysis of scientific and methodological literature, analysis of the content of curricula and textbooks, comparison, classification and modelling), empirical methods (pedagogical observation, questionnaires, analysis of students' creative products, expert assessment, tests and a pedagogical experiment) and mathematical-statistical methods (Pearson's χ^2 test and Student's t-test).

The pedagogical experiment was conducted in the 2025–2026 academic year in ascertaining, formative and control stages with the participation of grade 10 students from four general secondary schools in Tashkent city and Tashkent

region. The experimental group included 112 students and the control group 108 students. In the experimental group, the topics “Saturated hydrocarbons”, “Unsaturated hydrocarbons”, “Aromatic hydrocarbons”, “Alcohols and phenols”, “Aldehydes and carboxylic acids”, “Esters and fats”, “Carbohydrates”, “Nitrogen-containing organic compounds” and “Polymers” were taught using creative technologies, whereas in the control group they were taught using the conventional methodology.

Students’ creative and cognitive activity was assessed using four indicators: visuospatial representation of molecular structure; divergent search for isomers and solution variants; causal explanation of reaction mechanisms and properties of substances; and solving context-based problems in organic chemistry. Each indicator was scored on a 10-point scale, and the overall indicator was calculated as the arithmetic mean. Depending on its value, low (0–4.0 points), medium (4.1–7.0 points) and high (7.1–10 points) levels were distinguished. Open-ended tasks were assessed by three independent experts; the coefficient of concordance of their ratings (Kendall’s W) was 0.79.

Results

As the first result of the study, five features of organic chemistry content that serve as a basis for applying creative technologies were identified. First, the structure of organic substances belongs to the submicroscopic level, which cannot be observed directly, and understanding it requires modelling and visual imagination. Second, isomerism expresses the multiplicity of variants characteristic of organic chemistry: several different substances can correspond to one molecular formula. For example, the formula C_5H_{12} corresponds to three structural isomers (pentane, 2-methylbutane and 2,2-dimethylpropane), and the formula $C_4H_{10}O$ corresponds to four alcohols and three ethers, i.e. seven structural isomers in total. Such a task is divergent by its very nature. Third, the principle of homologous series and functional groups creates broad opportunities for reasoning by analogy. Fourth, the “structure – properties – applications” chain requires causal and predictive thinking from students. Fifth, organic chemistry content is very rich in real-life contexts related to medicine, food, energy, ecology and the local chemical industry, an aspect particularly emphasized by I.E. Shernazarov in his industry-integrated methodology [6].

On the basis of the identified features, the correspondence of creative educational technologies to organic chemistry topics and their didactic possibilities were systematized (Table 1).

Table 1 Correspondence of creative educational technologies to organic chemistry topics and their didactic possibilities

Technology	Organic chemistry topic	Didactic possibility and sample task
TRIZ	Polymers	Resolving a contradiction: "Polyethylene packaging must be strong, yet it must decompose quickly in nature." Students arrive at the idea of biodegradable polymers (e.g., polylactide).
Synectics (personal analogy)	Alcohols	"You are an ethanol molecule that has entered the human body. What happens to you in the liver?" Oxidation to acetaldehyde and its toxicity are explained.
SCAMPER	Esters and fats, soap	Reconsidering the composition and use of soap through the questions "substitute, combine, adapt" and justifying the idea of synthetic detergents.
Six Thinking Hats	Alcohols, carbohydrates (biofuels)	Discussing the use of bioethanol as a fuel from the perspectives of facts, feelings, risks, benefits, new ideas and conclusions.
Mind mapping	Hydrocarbons (review lesson)	Visual systematization of the relationships between the structure, isomerism, properties and applications of saturated, unsaturated and aromatic hydrocarbons.
Design thinking	Fats, carboxylic acids	Developing an idea for an environmentally friendly product made from cottonseed oil processing waste through the stages of empathy, problem definition, ideation, prototyping and testing.
Digital molecular modelling	Isomerism, aromatic hydrocarbons	Building 3D models of isomers in molecular editor software; visual analysis of the planar structure of the benzene molecule and the equivalence of its bonds.
STEAM project	Nitrogen-containing organic compounds, carbohydrates	Preparing an infographic and presentation entitled "Nitrogen compounds: from fertilizers to medicines" based on the products of local chemical enterprises.

According to the analysis, the didactic possibilities of creative technologies in teaching organic chemistry were generalized in the form of five main functions. The visualizing function makes the invisible molecular structure "visible"

through models, digital tools and mind maps, serving as a bridge between the macroscopic, submicroscopic and symbolic levels. The divergent-developmental function develops multi-variant thinking through searching for isomers, proposing synthesis routes and solving TRIZ problems. The integrative function connects organic chemistry with biology, medicine, ecology and technology. The motivational function strengthens cognitive interest by revealing the personal and social significance of the content and through game-based and creative elements. The reflective function serves the evaluation of ideas, the analysis of errors and awareness of one's own thinking process.

The methodology for applying creative technologies was distributed across the stages of the lesson. At the motivation stage, a problem situation or a synectic analogy was used; when studying new material, digital modelling and the divergent search for isomers; at the consolidation stage, TRIZ and Six Thinking Hats; at the review stage, mind mapping; and for homework and topic completion, STEAM projects and design thinking tasks. In selecting each technology, the content of the topic, the students' level of preparation and the aim of the lesson were taken into account.

The practical content of the methodology can be illustrated by a lesson on the topic "Alcohols". The lesson began with the personal analogy method of synectics: students imagined themselves as an ethanol molecule and described its "journey" through the human body. Then, under the teacher's guidance, the oxidation of ethanol in the liver to acetaldehyde and further to acetic acid, as well as the toxic effect of the intermediate product, were discussed. At the stage of studying new material, students used molecular editor software to search independently for all isomers with the composition $C_4H_{10}O$, classified them into alcohols and ethers, and explained, on the basis of the concept of hydrogen bonding, how the presence of the hydroxyl group affects the boiling point of alcohols. At the consolidation stage, the groups discussed the use of bioethanol as a motor fuel using the Six Thinking Hats technique. The lesson ended with reflection, in which students recorded the most unexpected discovery they had made and the aspects that remained unclear to them.

As a second example, a lesson on the topic "Polymers" conducted on the basis of TRIZ can be cited. Students were presented with a technical contradiction: "Disposable plastic packaging must be strong and water-resistant in order to protect products reliably, yet it must decompose quickly after use so as not to

pollute the environment.” Students first formulated the ideal final result and then searched for solutions using TRIZ principles (separation in time, changing properties and using natural resources). As a result, ideas such as biodegradable polymers like polylactide obtained from corn starch, systems for the separate collection of recyclable polymers and a transition to reusable packaging were put forward. Each idea was justified chemically in terms of the structure of the polymer, its monomer and the conditions of its degradation. The lesson enabled students to link their knowledge of polymerization and polycondensation reactions to a real environmental problem.

At the end of the experiment, the levels of students’ creative and cognitive activity were determined again. The results are presented in Table 2.

Table 2 Distribution of students’ creative and cognitive activity levels in the experimental and control groups

Group and stage	High		Medium		Low	
	n	%	n	%	n	%
EG (n=112), before	13	11.6	45	40.2	54	48.2
EG (n=112), after	34	30.4	58	51.8	20	17.9
CG (n=108), before	12	11.1	44	40.7	52	48.1
CG (n=108), after	17	15.7	49	45.4	42	38.9

Note: EG – experimental group, CG – control group.

Before the experiment, no significant difference was observed between the groups in the distribution of levels ($\chi^2 = 0.02$; $p > 0.05$). After the experiment, the proportion of students at the high level in the experimental group increased from 11.6% to 30.4%, while the proportion at the low level decreased from 48.2% to 17.9%. In the control group, the high level increased from 11.1% to 15.7%, and the low level decreased from 48.1% to 38.9%. The value $\chi^2 = 14.16$ calculated at the end of the experiment exceeds the critical value (5.99) at 2 degrees of freedom and a significance level of 0.05, which confirms the statistical significance of the difference between the groups.

The dynamics of the mean scores for the indicators of creative and cognitive activity are shown in Table 3.

Table 3 Mean scores for the indicators of creative and cognitive activity (10-point scale)

Indicator	EG before	EG after	CG before	CG after	t (before)	t (after)
Visuospatial representation	4.35±1.42	6.71±1.38	4.29±1.40	4.92±1.45	0.32	9.38
Divergent search for isomers and solution variants	3.98±1.51	6.54±1.44	4.05±1.47	4.68±1.50	0.35	9.38
Causal explanation of mechanisms and properties	3.62±1.36	5.88±1.41	3.57±1.39	4.21±1.43	0.27	8.72
Solving context-based problems	3.84±1.40	6.27±1.39	3.80±1.38	4.47±1.42	0.21	9.50

Note: $M \pm \sigma$ – mean and standard deviation; the critical value of the t-test is 1.97 ($p = 0.05$).

The table shows that before the experiment the differences between the groups were not significant for any indicator ($t < 1.97$), whereas after the experiment a statistically significant difference in favour of the experimental group emerged for all indicators ($t > 1.97$; $p < 0.001$). The greatest growth was observed in the divergent search for isomers and solution variants: the efficiency coefficient was 1.64 in the experimental group and 1.16 in the control group. For solving context-based problems, causal explanation and visuospatial representation, the efficiency coefficients in the experimental group were 1.63, 1.62 and 1.54, respectively.

The questionnaire results also showed positive changes: in the experimental group, the proportion of students who rated organic chemistry as an “interesting subject that is useful in life” increased considerably, and greater completeness of content and originality were observed in students’ creative products (mind maps, projects and models).

Discussion

The results show that the effectiveness of creative educational technologies in teaching organic chemistry depends on how well they are matched to the specific features of the subject content. The highest growth in the divergent search indicator is explained by the fact that the topic of isomerism is itself divergent in nature, and digital modelling tools allow students to build and check isomers “by

hand". This confirms that the parameters of divergent thinking described in J.P. Guilford's theory [28] can be developed on the basis of subject content.

The considerable growth in visuospatial representation is consistent with the conclusion of H.-K. Wu and P. Shah that molecular models and computer visualization develop visuospatial thinking [25], and with A. Johnstone's idea of the need to build bridges between the three levels of chemical knowledge [21]. At the same time, the relatively lower absolute values of the indicator for the causal explanation of mechanisms and properties show that mastering reaction mechanisms is the most difficult task in organic chemistry, and that the risk of mechanical memorization noted by G. Bhattacharyya and G. Bodner [23] is not completely eliminated even when creative technologies are used. In this respect, it is advisable to enrich the methodology with tasks specifically aimed at developing representational competence [24].

The high growth in the indicator for solving context-based problems is consistent with I.E. Shernazarov's conclusions on the effectiveness of his industry-integrated methodology based on the STEAM approach [6; 7]. Linking organic chemistry content to local chemical enterprises, medicines and food products increases the personal significance of knowledge for students, which fully meets the principle of relevance substantiated by I. Eilks and A. Hofstein [26]. I.E. Shernazarov's conclusions on the role of creative thinking tasks in developing functional literacy [8; 9] were also confirmed by the results of the study: students who worked with creative technologies solved context-based tasks not only correctly but also in several well-justified ways.

The results also showed that the psychological characteristics of students aged 15–16 influence the effectiveness of creative technologies. At this age, abstract logical thinking, the desire to justify one's own point of view and interest in choosing a future profession are actively developing. Therefore, tasks with a professional context, for example solving a problem in the role of a pharmacist, food technologist or chemical engineer, aroused particularly high interest among students. In group work, mutual cooperation and the exchange of ideas also involved in the creative process those students who were less active in individual work. This result is consistent with T. Amabile's conclusions that intrinsic motivation and a supportive social environment are important conditions for creativity [29].

Some difficulties in applying creative technologies were also identified. Technologies such as TRIZ and design thinking require a lot of lesson time; therefore, it is more effective to use them in project work and extracurricular activities. Digital modelling depends on the school's material and technical resources; where computers are lacking, ball-and-stick molecular model kits serve as an alternative. In addition, the effect of creative technologies depends directly on the teacher's preparation: rather than mechanically following the stages of a technology, the teacher must be able to guide students' ideas in a chemically correct direction. This requires strengthening special training in creative technologies within the system of preparing future chemistry teachers, an issue also raised in I.E. Shernazarov's works on the functional literacy of future chemistry teachers and their preparation for international assessment studies [11; 15].

The limitations of the study include the fact that the experiment was conducted over one academic year with a relatively limited sample, and that the assessment of open-ended tasks involves a certain degree of subjectivity. In future research, a promising direction is the integration of artificial intelligence tools, virtual laboratories and adaptive platforms with creative technologies in teaching organic chemistry.

Conclusion and Recommendations

Based on the study, the following conclusions were drawn. First, such features of organic chemistry content as the invisibility of submicroscopic structure, the multiplicity of variants in isomerism, the principle of homologous series and functional groups, the "structure – properties – applications" chain and the richness of real-life contexts serve as an objective didactic basis for applying creative educational technologies.

Second, the didactic possibilities of creative educational technologies in teaching organic chemistry are manifested in their visualizing, divergent-developmental, integrative, motivational and reflective functions. TRIZ, synectics, SCAMPER, Six Thinking Hats, mind mapping, design thinking, digital molecular modelling and STEAM projects are most effective when applied in alignment with specific topics of organic chemistry.

Third, the effectiveness of the methodology developed on the basis of I.E. Shernazarov's scientific views on the integrative approach, STEAM education

and functional literacy was confirmed by a pedagogical experiment: in the experimental group, the proportion of students with a high level of creative and cognitive activity increased from 11.6% to 30.4%, and the difference between the groups was statistically significant ($\chi^2 = 14.16 > 5.99$).

Based on the results of the study, it is recommended to include a system of tasks based on creative technologies in organic chemistry textbooks and teaching guides, to provide schools with molecular model kits and digital modelling tools, to introduce a module entitled “Creative educational technologies in teaching organic chemistry” into professional development courses for chemistry teachers, and to develop context-based learning materials in cooperation with local chemical enterprises.

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