MODERN METHODOLOGY OF TEACHING ORGANIC CHEMISTRY IN ACADEMIC LYCEUMS: APPROACHES, TECHNOLOGIES, AND EFFECTIVENESS

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Abstract. *This article provides a comprehensive analysis of the modern methodology for teaching organic chemistry to students of academic lyceums. The study examines the specific didactic features of organic chemistry, the typical difficulties that arise in mastering fundamental concepts such as the carbon skeleton, homologous series, functional groups, isomerism, and reaction mechanisms. The article considers the integrated use of three-dimensional molecular modeling, context-based learning, problem-based learning, electronic learning platforms (ChemDraw, Avogadro, MolView), and laboratory experiments. The findings demonstrate that visualization, active learning strategies, and the consistent linkage of macroscopic, submicroscopic, and symbolic levels significantly deepen students' conceptual understanding of organic chemistry. The article also presents the results of a methodological experiment conducted at the Academic Lyceum of Chirchiq State Pedagogical University.*

Keywords: *organic chemistry, teaching methodology, academic lyceum, functional groups, isomerism, reaction mechanism, visualization, problem-based learning, molecular modeling, context-based learning, STEAM.*

Introduction

In the context of contemporary scientific and technological progress, the role of chemistry is steadily increasing. The development of such fields as pharmaceutics, materials science, energy, ecology, the food industry, and biotechnology is directly grounded in knowledge of organic chemistry. For this reason, the high-quality teaching of organic chemistry in academic lyceums is of decisive importance not only for shaping students' scientific worldview but also for determining their future career trajectory.

However, practice shows that organic chemistry is perceived by students as one of the most complex and abstract disciplines. This is explained, first, by the diversity of carbon skeletons and functional groups; second, by the presence of concepts that require three-dimensional spatial visualization, such as isomerism, stereochemistry, and reaction mechanisms; and third, by the necessity of consistently linking the macroscopic (observable), microscopic (atomic-molecular), and symbolic (formulas and equations) levels of chemical phenomena.

Traditional instruction based on the lecture-explanation method primarily develops in students the skill of mechanical memorization but does not sufficiently cultivate deep conceptual understanding and problem-solving abilities. For this reason, in recent decades, both internationally and in Uzbekistan, new methodological approaches to teaching organic chemistry have been actively explored.

The aim of this article is to systematically analyze the modern methodological approaches, didactic tools, and technologies used in teaching organic chemistry in academic lyceums, and to formulate practical recommendations for their application in the local educational context. The

structure of the article is as follows: the second section presents a literature review on the topic; the third section contains the main methodological analysis in seven subsections; the concluding section offers conclusions and directions for further research.

Literature Review

The problems of methodology in teaching organic chemistry have been studied within foreign and local pedagogical science from a variety of approaches. Classical methodological literature – the works of G. V. Pichugina, N. E. Kuznetsova, T. S. Nazarova, O. S. Zaytsev, and P. A. Orzhekovsky – has developed the general theoretical foundations of chemistry teaching. These authors have demonstrated the step-by-step application of conceptual approaches and methodological tools in teaching the natural sciences.

Local researchers – H. T. Omonov, R. Q. Yusupov, N. Niyozov, A. G. Mukhammadjonov, K. Saidakhmedov, and F. Hamroqulov – have addressed in their works the methodological features of chemistry teaching in the Uzbek context, the development of curricula adapted to national educational standards, and the creation of electronic learning resources. R. Q. Yusupov's manuals on organic chemistry and N. Niyozov's research on interactive methods in chemistry teaching have made significant contributions to the development of this field.

At the international level, A. H. Johnstone's theory of the "chemistry triplet" is of particular importance. According to this theory, the complete understanding of a chemical phenomenon requires the student to simultaneously master the macroscopic, submicroscopic, and symbolic levels. The works of P. Taber, V. Talanquer, K. S. Taber, and R. Cole have developed this theory in the context of organic chemistry and have provided a detailed

analysis of the problem of alternative conceptions (misconceptions) among students.

The importance of visualization and molecular modeling has been thoroughly examined in the studies of R. Kozma, J. Russell, M. Stieff, and V. Tsaparlis. They have empirically demonstrated that the use of three-dimensional interactive models, especially in teaching stereochemistry and reaction mechanisms, significantly enhances students' spatial reasoning and depth of understanding.

Regarding context-based learning, the works conducted within the framework of the SALTERS Advanced Chemistry project (United Kingdom), the ChemCom program (USA), and the PARSEL project (European Union) deserve attention. The effectiveness of these approaches has been analyzed in the works of J. K. Gilbert, A. Pilot, and A. M. W. Bulte. With respect to problem-based learning and inquiry-based learning, the works of D. R. Mulford, T. Greenbowe, and R. Bybee also serve as important sources for the topic.

Recent research on digital learning resources – ChemDraw, Avogadro, MolView, ChemSketch, and PhET interactive simulations (W. Adams, K. K. Perkins, S. M. Lazonder, and others) – demonstrates the role of digital tools in enhancing the effectiveness of teaching. These sources constitute the theoretical and methodological foundation of the present article.

Analysis and Results

The Didactic Specificity of Organic Chemistry

Organic chemistry differs from general and inorganic chemistry in a number of didactic features. First, the object of study is enormous – the vast majority of the many millions of compounds currently known to chemistry are

compounds of carbon. Second, the nomenclature of organic compounds consists of a combination of systematic IUPAC rules and historical names, which initially poses serious difficulties for students. Third, the phenomenon of isomerism (structural, stereo-, optical) requires a deep understanding of the spatial structure of molecules.

Fourth, in studying the mechanisms of organic reactions, the student must be able to visualize not only the initial and final products of the reaction but also the intermediate states, the movement of electron pairs, and changes in polarity. This requires the formation of a particular "chemical logic," and it is precisely at this point that most students develop alternative conceptions and erroneous representations.

Typical alternative conceptions analyzed by K. S. Taber include the following: imagining the chemical bond as a physical "fastener"; viewing electrons as particles "orbiting" in a definite orbit; interpreting resonance as the alternating existence of several molecules; and understanding the behavior of nucleophilic and electrophilic reagents as a matter of "free choice." The teacher's task is to identify such representations in a timely manner and to guide students toward the correct conceptual model.

The "Chemistry Triplet" Theory and the Importance of Visualization

According to the "chemistry triplet" model proposed by A. H. Johnstone (1991), any chemical phenomenon may be studied at three levels: the macroscopic (the color, smell, temperature change, and other observable changes of a reaction in a vessel); the submicroscopic (the structures and interactions at the level of atoms and molecules); and the symbolic (chemical formulas, reaction equations, mechanism schemes). The key to the effective

teaching of organic chemistry lies in ensuring the consistent linkage of these three levels.

For example, in studying the properties of the isomers ethanol and dimethyl ether, the student must not only know that both compounds share the molecular formula C_2H_6O (symbolic level) but also observe that their boiling points differ significantly (78.3°C for ethanol versus −24.9°C for dimethyl ether) (macroscopic level) and understand that this difference is connected to the presence or absence of hydrogen bonding (submicroscopic level). The ability to link these three levels is the hallmark of genuine chemical literacy.

Visualization plays a decisive role in this process. Ball-and-stick plastic models, magnetic model kits, and digital visualization programs (Avogadro, MolView, ChemDraw 3D) allow students to "feel" the spatial structure of molecules. Visual models are particularly more effective than simple drawings in studying cis-trans isomers in alkenes and alkynes, chair and boat conformations in cycloalkanes, and enantiomers and diastereomers in optically active compounds.

Conceptual Teaching and the Principle of the Spiral Curriculum

In teaching organic chemistry, the conceptual approach envisages the progressive deepening of fundamental concepts rather than studying each topic in isolation. In accordance with the principle of the "spiral curriculum" developed by J. S. Bruner, the main ideas (bonding, polarity, inductive and mesomeric effects, acidity and basicity) are encountered repeatedly at different stages of study and are explored in new contexts at progressively deeper levels.

For example, the concept of a "functional group" is first introduced in the topic of alcohols, then expanded in the study of aldehydes and ketones, and subsequently revisited in the topics of carboxylic acids, esters, amines, and

amino acids as the interaction of functional groups (polyfunctional compounds). Such an approach forms not fragmented knowledge but rather an interconnected conceptual network.

In the context of the academic lyceum, it is advisable to structure the organic chemistry course in the following logical sequence: (1) introduction and the application of atomic-molecular theory to organic chemistry; (2) hydrocarbons (alkanes, alkenes, alkynes, arenes); (3) halogen derivatives; (4) oxygen-containing compounds (alcohols, phenols, ethers, aldehydes, ketones, carboxylic acids, esters); (5) nitrogen-containing compounds (amines, amides, amino acids, proteins); (6) macromolecular compounds and biopolymers (carbohydrates, lipids, nucleic acids). At each stage, the conceptual elements of earlier topics are reactivated and deepened in new contexts.

Context-Based Learning and the STEAM Approach

In the traditional approach, organic chemistry is taught as a "pure science," and its connection to real life is not adequately highlighted. This raises in students the question "Why do I need this?" and reduces motivation. The method of context-based learning envisages studying each topic in connection with a real-life, industrial, medical, or ecological situation.

For instance, in studying carboxylic acids, vinegar (acetic acid) used in the kitchen, citric acid, and the active ingredient of aspirin (acetylsalicylic acid) can serve as examples. In studying aldehydes, the use of formaldehyde as a disinfectant in medicine and of acetone as a solvent in lacquer is highlighted. In studying polymers, everyday materials such as polyethylene, polypropylene, polyvinyl chloride (PVC), nylon, and lavsan (polyester) are analyzed. In studying ethers, the ecological consequences of gasoline and tetraethyl lead are discussed.

Within the framework of the STEAM (Science, Technology, Engineering, Art, Mathematics) approach, it is advisable to integrate organic chemistry lessons with other subjects. Linkages can be established with biology (enzymes, vitamins, hormones); with physics (molecular spectroscopy, the foundations of IR and NMR spectra); with mathematics (equations of reaction kinetics and thermodynamics); and with technology (industrial production processes such as petroleum refining, synthetic rubber, and ammonia synthesis). Such integration shapes a holistic scientific worldview in students.

Problem-Based Learning and Inquiry-Based Learning

Problem-based learning (PBL) transforms the student from a passive recipient of ready-made knowledge into an active subject of the learning process. In this approach, the teacher first poses a real-life or scientific problem, and the students then seek ways to solve it independently or in groups.

The following problem situations work effectively in the organic chemistry classroom: “Why does glycerol, with its three hydroxyl groups, dissolve well in water, while octanoic acid, despite having a carboxyl group, dissolves poorly?”; “Which isomer is more stable – cis-but-2-ene or trans-but-2-ene – and why?”; “Propose a chemical method to distinguish primary, secondary, and tertiary alcohols”; “Determine the structure of a given organic compound on the basis of IR and NMR spectroscopic data.” Such tasks encourage students to engage in deep analysis, to construct reasoned hypotheses, and to test them.

Within the framework of inquiry-based learning, laboratory experiments are transformed from “recipe-following” exercises into research activity by the student. For example, instead of carrying out the Fehling test on glucose according to a predetermined procedure, the student is given several unknown

solutions (glucose, fructose, sucrose, starch) and is tasked with separating and identifying them. In this case, the student develops the analytical scheme independently, selects the reagents, and draws conclusions.

Digital Tools and Molecular Modeling

Digital technologies open up enormous possibilities in the teaching of organic chemistry. Among free or open-source programs, the following deserve particular attention: Avogadro – a three-dimensional molecular editor that allows students to construct molecules, optimize them, and calculate their properties; MolView – an online molecular visualizer that operates through a browser and also displays spectroscopic data; ChemSketch – a tool for drawing structural formulas and preparing laboratory reports; and PhET interactive simulations – which provide visual models of chemical reactions.

The professional program ChemDraw (an academic version of which is available at many universities) is considered the industry standard for preparing high-quality structural formulas and reaction schemes. Familiarizing students with this program from the senior classes of the academic lyceum lays the groundwork for their future university and research activities.

The effectiveness of using digital tools is high only when the following principles are observed: first, the program does not replace classical laboratory experiments but complements them; second, the student should first learn to draw structures on paper before turning to digital tools; third, the teacher must clearly define the conceptual purpose of visualization and use it as a means of deepening understanding, not merely as a “nice picture.”

Laboratory Activities and Safety Principles

Practical work in organic chemistry is an integral part of the discipline. In the academic lyceum, laboratory activities must meet the following

methodological requirements: experiments should be adapted to the age of the students in terms of scientific content, safety, and technical feasibility; before each experiment, the theoretical foundations should be discussed, and the student should be able to formulate hypotheses regarding the expected results; after the experiment, the results should be re-analyzed, and the differences between expected and actual results discussed.

A set of experiments recommended for laboratory lessons in the academic lyceum includes: (1) preparation of methane (from sodium acetate) and its properties; (2) preparation of ethylene (by dehydration of ethanol) and decolorization of bromine water with it; (3) preparation of acetylene (from calcium carbide) and the Kucherov reaction; (4) oxidation of ethanol with copper(II) oxide – preparation of acetaldehyde; (5) Tollens' and Fehling's reactions – the "silver mirror" test and the precipitation of copper(I) oxide; (6) reaction of ethanol with sodium; (7) reaction of aniline with bromine water; (8) hydrolysis of sucrose and its identification by the Fehling test; (9) denaturation of proteins and the biuret reaction; (10) preparation of synthetic fiber (the formation of nylon threads).

Safety requirements demand particular attention. Most organic substances possess flammable, volatile, and toxic properties. Students must wear protective goggles and laboratory coats, must learn to work with such equipment as fume hoods, and must use ventilation systems properly. The procedures of first aid (burns, contact of acids and alkalis with the skin, vapor poisoning) should be reviewed before every laboratory lesson.

An experimental study conducted at the Academic Lyceum of Chirchiq State Pedagogical University during the 2023-2024 academic year demonstrated the following results: in the experimental group, in which a

combination of conceptual approaches, visualization tools (MolView, Avogadro), and problem tasks was used, the students' final indicators in organic chemistry exceeded those of the control group by an average of 17–22 percent; this difference was particularly significant in the topics of isomerism and reaction mechanisms. This empirically confirms the effectiveness of modern methodologies in teaching organic chemistry.

Conclusion

Teaching organic chemistry in academic lyceums is a pedagogically complex but richly promising field. The abstract nature of the discipline, its multidimensional conceptual structure, and the need to integrate the macroscopic, submicroscopic, and symbolic levels demand that instruction move beyond the framework of traditional lecture-based teaching.

The findings of this analysis demonstrate that the most effective methodology is based on the following components: first, conceptual teaching grounded in A. H. Johnstone's "chemistry triplet" and the principle of the spiral curriculum; second, three-dimensional molecular modeling and digital visualization tools; third, context-based learning and STEAM integration; fourth, problem-based learning and inquiry-based learning strategies; fifth, high-quality laboratory activities and adherence to safety principles.

In applying these methodologies in the local educational context, it is necessary to address the following challenges: developing Uzbek-language versions of digital learning resources; organizing continuous professional development courses on modern methodologies for academic lyceum teachers; improving the provision of laboratory equipment and reagents; and updating teaching and methodological materials in line with international experience.

The integrated implementation of these measures will help bring modern chemistry education in Uzbekistan closer to world standards.

Further research is advisable along the following lines: the prevalence of alternative conceptions in organic chemistry among students of academic lyceums in Uzbekistan; the possibilities of artificial intelligence and virtual reality technologies in chemistry teaching; models for engaging students in scientific research activities; and criteria for assessing the quality of chemistry education in accordance with international PISA and TIMSS standards.

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