CHEMICAL SCIENCES

DEVELOPMENT OF STUDENTS' RESEARCH AND ANALYTICAL SKILLS IN THE STUDY OF ORGANIC CHEMISTRY THROUGH THE USE OF ARTIFICIAL INTELLIGENCE

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Abstract

This article examines the theoretical and methodological foundations of using artificial intelligence to develop students' research and analytical skills in the study of organic chemistry. The main learning difficulties are analyzed, including understanding reaction mechanisms and the relationship between molecular structure and properties. A teaching methodology based on the integration of MolView and ChatGPT tools is proposed. This approach is aimed at developing skills in structural analysis, reaction prediction, synthesis planning, and scientific reasoning. The scientific novelty lies in the development of an integrated model combining visualization tools and artificial intelligence in organic chemistry education.

Keywords: artificial intelligence, organic chemistry, teaching methodology, analytical skills, research skills, digital education.

Introduction

In the modern education system, the use of digital technologies is an important tool for increasing students' active participation in the learning process. In particular, artificial intelligence technologies are being rapidly integrated into education. These changes open up new opportunities, especially in teaching natural sciences, including organic chemistry [1, p. 3-4].

Organic chemistry is one of the most complex subjects, as it requires not only theoretical knowledge but also a high level of analytical and research thinking. Often, students tend to memorize reactions, but they face difficulties in understanding their mechanisms [2, p. 1108].

In this regard, the use of artificial intelligence in teaching organic chemistry enhances students' cognitive engagement and contributes to the development of their research and analytical skills [3, p. 5].

Theoretical Background

The modern educational paradigm focuses not only on acquiring knowledge but also on developing higher-order thinking skills. From this perspective, the formation of analytical and research skills is one of the main objectives of teaching organic chemistry.

The Essence of Analytical Skills. Analytical skills are a set of abilities that enable a learner to organize, analyze, compare, and draw conclusions from information [4, p. 12]. In organic chemistry, these skills manifest in analyzing molecular structures, identifying functional groups, explaining the relationship between structure and properties, and predicting reaction outcomes [5, p. 582]. Analytical thinking is especially important in organic chemistry because students must not only memorize formulas but also understand their internal logic. For example, a change in one functional group can alter the chemical properties of the entire molecule.

The Content of Research Skills. Research skills describe a learner's ability to engage in scientific inquiry. These include identifying a problem, formulating a hypothesis, solving it through experimental or theoretical approaches, analyzing and evaluating results, and drawing conclusions. In organic chemistry, these skills develop through constructing synthesis pathways, explaining reaction mechanisms, and comparing alternative solutions [6, p. 693].

Features of Teaching Organic Chemistry. While studying organic chemistry, students face several challenges: difficulty visualizing molecular spatial structures, complexity in understanding reaction mechanisms, challenges in identifying the relationship between structure and properties, and a tendency to memorize reactions mechanically. To address these issues, it is important to use visualization and interactive methods in teaching.

The Role of Visualization. Visualization is one of the key tools in teaching organic chemistry. The use of 3D molecular models helps develop students' spatial thinking. Tools such as MolView allow for accurate representation of molecular structures, visualization of bonds, understanding of isomerism, and simulation of reactions. Visualization transforms theoretical knowledge into concrete understanding and increases student interest in the subject.

Pedagogical Potential of Artificial Intelligence. Artificial intelligence technologies open new opportunities in modern education. Systems like ChatGPT can support personalized learning paths, provide immediate feedback, explain complex topics, and analyze student errors [1, p. 4]. The main advantage of AI is its interactivity and adaptability. It responds according to each student's level and individualizes the learning process [7, p. 7].

Artificial Intelligence as an "Intelligent Tutor". In the learning process, ChatGPT can be considered an "intelligent tutor." It asks guiding questions, stimulates thinking, teaches through explanation rather than giving direct answers, and supports reflection. This approach aligns with constructivist learning theory, where learners actively construct their own knowledge.

Constructivist and Digital Learning Theories. The proposed methodology is based on constructivist theory, which states that learners do not receive knowledge passively but construct it through experience and active engagement. In addition, the methodology relies on principles of digital learning: interactivity, multimedia learning, and personalized education [8, p. 43].

Theoretical Basis for Integrating MolView and ChatGPT. The combined use of MolView and ChatGPT integrates two cognitive processes: visual perception (MolView) and analytical and verbal processing (ChatGPT). This integration promotes deeper understanding, as students simultaneously see, analyze, and explain information [8, p. 316].

The theoretical foundations discussed above demonstrate the effectiveness of integrating artificial intelligence and visualization tools in teaching organic chemistry. This approach enables the systematic development of students' analytical and research skills [1, p. 4].

Proposed Methodology

The proposed methodology is based on the integrated use of the MolView visualization tool and the ChatGPT artificial intelligence system in teaching organic chemistry. It aims not only to enhance theoretical knowledge but also to systematically develop students' analytical and research thinking skills [1, p. 4].

The methodology has a staged structure, where each stage is designed to achieve specific didactic goals. In this process, the learner acts not as a passive listener but as an active researcher.

<u>Stage 1: Molecular Visualization</u>

At this stage, MolView is used as the main tool. Students independently construct or analyze the structure of a given organic compound. They:

- draw the 2D structure of the molecule;
- convert it into a 3D format;
- observe the spatial arrangement of atoms;
- study bond angles and geometry.

The pedagogical significance of this stage lies in transforming abstract chemical concepts into concrete visual representations, leading to a deeper understanding of molecular structures.

<u>Stage 2: Structural and Analytical Analysis</u>

At this stage, students conduct a comprehensive analysis of the molecule based on a predefined algorithm or checklist. They:

- identify functional groups;
- determine the class of the compound;
- analyze types of isomerism;
- predict reactivity;
- identify possible chemical reactions.

The teacher plays a guiding role, encouraging students to draw their own conclusions rather than providing ready-made answers [6, p. 693].

<u>Stage 3: Analysis with Artificial Intelligence</u>

At this stage, ChatGPT is used as an "intelligent learning assistant." Students:

- input the IUPAC name or structure obtained from MolView;
- interact with AI using prepared prompts;
- compare AI-generated answers with their own results;
- identify and correct errors.

The AI:

- provides explanations;
- asks additional questions;
- suggests alternative solutions;
- guides the student's thinking process.

A key aspect of this stage is critical thinking: students do not accept AI responses uncritically but analyze and evaluate them [4, p. 15].

<u>Stage 4: Research Tasks</u>

At this stage, students perform higher-level tasks involving research activities [6, p. 692]. They:

- propose multiple synthesis routes for a given substance;
- compare their efficiency;
- explain reaction mechanisms;
- draw scientifically grounded conclusions.

Example tasks:

- "Propose two synthesis routes and choose the most efficient one."
- "Identify errors in the given reaction."
- "Predict the reaction product and justify your answer."

This stage develops elements of scientific thinking such as hypothesis formation, reasoning, and conclusion [6, p. 693].

Pedagogical Features and Effectiveness of the Methodology. The proposed methodology has several important features. First, it ensures personalized learning tailored to each student's level and needs [7, p. 7]. Second, it emphasizes the active role of the learner. Third, it is based on the integration of visualization and analysis, enabling deeper understanding. Fourth, immediate feedback enhances learning efficiency. Fifth, it promotes a research-oriented approach, encouraging students to explore and construct knowledge independently [6, p. 692].

This methodology simplifies the understanding of complex concepts by combining visual and analytical approaches. It increases student engagement through interactive tools and AI capabilities. It allows immediate identification and correction of errors, leading to deeper learning [7, p. 7]. It also connects theoretical knowledge with practical application and fosters a research culture by encouraging questioning, hypothesis generation, experimentation, and conclusion .

Description of Integrated Tasks. The methodology includes five tasks; below are brief descriptions of three of them.

Task 1: Verification of Markovnikov's Rule. The student asks ChatGPT to predict the product of HBr addition to propene. Then, using MolView, they compare propene and the predicted product (2-bromopropane). They visually confirm that bromine attaches to the second carbon. This task develops prediction (research) and comparison (analytical) skills.

Task 2: Chirality and Enantiomers. ChatGPT provides theoretical explanations of chiral molecules and enantiomers. The student constructs D-glyceraldehyde in MolView and creates its mirror image (L-isomer), verifying that the two cannot be superimposed. This develops virtual experimentation skills.

Task 3: Analysis of a Complex Molecule (Aspirin). ChatGPT identifies the functional groups in aspirin. The student then locates these groups in the MolView model and studies spatial features such as the aromatic ring and functional group orientation. By combining both sources, the student performs a comprehensive analysis.

Pedagogical Advantages of the Methodology. Compared to separate use, the integrated methodology has several advantages. It ensures the synthesis of theory and visualization, deepening understanding. It develops critical thinking, as students evaluate AI responses rather than accept them blindly. It compensates for the limitations of each tool: ChatGPT lacks spatial visualization, while MolView lacks theoretical explanations. Together, they complement each other.

Moreover, each task follows a full scientific inquiry cycle: hypothesis (ChatGPT), visual verification (MolView), comparison, and conclusion, helping students adopt the logic of real research.

Conclusion

This article proposes a methodology for integrating ChatGPT and MolView in teaching organic chemistry. Compared to separate use, the integrated approach more effectively develops students' analytical and research skills. Three integrated tasks were designed, and their pedagogical logic was described.

The proposed methodology can be applied in higher education organic chemistry courses. Future research will involve quantitative evaluation through pedagogical experiments.

References:

1. Kasneci, E., Sebler, K., Küchemann, S., et al. (2023). ChatGPT for good? On opportunities and challenges of large language models for education. Learning and Individual Differences, 103, 102274.

2. Taagepera, M., & Noorbit, G. (2002). The relationship between structure and reactivity in organic chemistry: A study of student understanding. Journal of Chemical Education, 79(9), 1107–1112.

3. Cotton, D. R. E., Cotton, P. A., & Shipway, J. R. (2023). Chatting and cheating: Ensuring academic integrity in the era of ChatGPT. Innovations in Education and Teaching International.

4. Facione, P. A. (2015). Critical thinking: What it is and why it counts. Insight Assessment.

5. Christiansen, C., Nystrøm, B., & Ulriksen, L. (2019). Learning challenges in organic chemistry. Chemistry Education Research and Practice, 20(3), 579–592.

6. Harland, T. (2020). Teaching research skills: Design, process and assessment. Higher Education Research & Development, 39(4), 690–703.

7. Rudolph, J., Tan, S., & Tan, S. (2023). ChatGPT: Bullshit spewer or the end of traditional assessments in higher education? Journal of Applied Learning & Teaching, 6(1).

8. Mayer, R. E. (2021). Multimedia learning (3rd ed.). Cambridge University Press.