

Didactic potential of a problem-based approach in teaching chromatographic methods

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Abstract: The integration of problem-based learning (PBL) into the teaching of chromatographic methods represents a promising approach to enhancing students' analytical thinking and practical competencies in analytical chemistry. This study explores the didactic potential of problem-based approaches in teaching chromatography, focusing on their role in improving conceptual understanding, problem-solving skills, and student engagement. Chromatographic techniques, such as paper, thin-layer, and column chromatography, are inherently suitable for problem-oriented instruction due to their experimental and interpretative nature. The research analyzes the effectiveness of incorporating real-life analytical scenarios and inquiry-based tasks into the learning process. The findings indicate that problem-based learning fosters deeper comprehension of separation mechanisms, enhances students' ability to interpret chromatographic data, and promotes independent learning. Furthermore, it supports the development of critical and scientific thinking skills essential for future chemists and educators. The study concludes that the systematic implementation of problem-based approaches significantly increases the didactic value of chromatographic instruction and contributes to the formation of key professional competencies in students.

Keywords: problem-based learning, chromatographic methods, analytical chemistry education, didactic potential, critical thinking, inquiry-based learning, scientific competence, chromatography techniques

INTRODUCTION

In modern chemical education, the emphasis has shifted from the passive acquisition of knowledge to the active development of students' cognitive and professional competencies. Analytical chemistry, as a fundamental discipline, plays a crucial role in forming students' scientific worldview, experimental skills, and analytical thinking. Among its various branches, chromatographic methods occupy a central position due to their wide application in environmental analysis, pharmaceuticals, food quality control, and biochemical research. Therefore, effective teaching of chromatography is essential for preparing future specialists capable of solving real-world chemical problems.

Traditional teaching approaches in analytical chemistry often rely on the transmission of theoretical knowledge and algorithmic laboratory procedures. However, such methods may not sufficiently develop students' ability to analyze complex situations, interpret experimental data, and make independent decisions. In this context, the integration of problem-based learning (PBL) into the teaching process has gained increasing attention. PBL is an instructional strategy that engages students in solving meaningful and context-based problems, thereby promoting active learning, critical thinking, and deeper conceptual understanding.

Chromatographic methods, including paper chromatography, thin-layer chromatography (TLC), gas chromatography (GC), and high-performance liquid chromatography (HPLC), provide an ideal platform for implementing problem-based approaches. These techniques inherently involve interpretation of separation processes, identification of compounds, and evaluation of experimental conditions, which can be effectively transformed into problem-oriented learning scenarios. By presenting students with real-life analytical challenges - such as determining the composition of mixtures or optimizing separation parameters - educators can stimulate inquiry, hypothesis formation, and evidence-based reasoning.

Despite the recognized benefits of problem-based learning, its didactic potential in the context of teaching chromatographic methods remains insufficiently explored. This study aims to investigate the pedagogical effectiveness of problem-based approaches in teaching chromatography and to identify their impact on students' learning outcomes. The research focuses on analyzing how problem-based tasks contribute to the development of analytical competencies, enhance motivation, and improve the overall quality of chemical education.

MATERIAL AND METHODS

This study was conducted within the framework of higher education in chemistry, involving undergraduate students enrolled in analytical chemistry courses. A total of 48 students participated in the research and were divided into two groups: an experimental group and a control group. The experimental group was taught using a problem-based learning (PBL) approach integrated into the instruction of chromatographic methods, while the control group received traditional lecture-based and algorithmic laboratory instruction.

The instructional content focused on key chromatographic techniques, including paper chromatography, thin-layer chromatography (TLC), and basic principles of gas and liquid chromatography. In the experimental group, specially designed problem-based tasks were implemented. These tasks were based on real-life analytical scenarios, such as identifying unknown components in mixtures, selecting appropriate stationary and mobile phases, and interpreting chromatographic results. Students were encouraged to formulate hypotheses, design experimental procedures, and analyze obtained data independently or in small collaborative groups.

Data collection methods included pre- and post-tests to assess students' knowledge and analytical skills, as well as observation of classroom activities and student engagement. Additionally, structured questionnaires were used to evaluate students' perceptions of the learning process and their motivation levels.

The effectiveness of the implemented approach was evaluated using comparative statistical analysis of learning outcomes between the two groups. Qualitative analysis was also conducted to assess the development of critical thinking, problem-solving abilities, and practical competencies in chromatography. This mixed-method approach ensured a comprehensive evaluation of the didactic potential of problem-based learning in teaching chromatographic methods.

RESULTS AND DISCUSSION

The implementation of a problem-based learning (PBL) approach in teaching chromatographic methods demonstrated a significant positive impact on students' academic performance, analytical thinking, and engagement in the learning process. The comparative analysis of pre-test and post-test results revealed that students in the experimental group showed a markedly higher improvement in understanding chromatographic principles compared to those in the control group. In particular, their ability to explain separation mechanisms, such as adsorption, partition, and ion-exchange processes, improved substantially.

Students exposed to problem-based tasks demonstrated enhanced skills in interpreting chromatographic data, including the analysis of retention factors (R_f values), peak identification, and evaluation of separation efficiency. Unlike the control group, which often relied on memorized procedures, the experimental group showed a deeper conceptual understanding and greater flexibility in applying theoretical knowledge to unfamiliar situations. For example, when presented with complex mixture analysis tasks, students were able to justify the selection of appropriate chromatographic methods and optimize experimental conditions based on chemical properties of analytes.

The use of real-life scenarios significantly increased students' motivation and interest in the subject. Classroom observations indicated that students in the experimental group were more actively involved in discussions, collaborative problem-solving, and experimental planning. This active participation contributed to the development of critical thinking and scientific reasoning skills. Moreover, students became more confident in making independent decisions, which is a key competency in analytical chemistry.

Qualitative feedback from questionnaires further supported these findings. A majority of students reported that problem-based tasks made the learning process more meaningful and helped them better understand the practical relevance of chromatography. They also noted improvements in teamwork, communication, and self-directed learning abilities.

From a didactic perspective, the integration of PBL into chromatography instruction proved to be highly effective. It facilitated the transition from teacher-centered to student-centered learning, where the instructor acted as a facilitator rather than a sole source of knowledge. This approach aligns with modern educational paradigms focused on competency-based learning and functional literacy.

The results confirm that problem-based learning significantly enhances the quality of teaching chromatographic methods by promoting deeper understanding, improving analytical competencies, and increasing student engagement. These findings highlight the importance of incorporating innovative pedagogical strategies into analytical chemistry education.

CONCLUSION

The findings of this study clearly demonstrate that the integration of a problem-based learning (PBL) approach into the teaching of chromatographic methods significantly enhances the effectiveness of analytical chemistry education. The application of problem-oriented tasks not only improves students' theoretical understanding of chromatographic principles but also strengthens their ability to apply knowledge in practical and real-life contexts. This is particularly important in analytical chemistry, where the interpretation of experimental data and the selection of appropriate methods are essential professional skills.

The results confirm that students exposed to PBL exhibit higher levels of critical thinking, analytical reasoning, and independent decision-making compared to those taught using traditional instructional methods. The active involvement of students in problem-solving processes fosters deeper cognitive engagement and promotes long-term knowledge retention. Moreover, the collaborative nature of problem-based tasks contributes to the development of communication skills and teamwork, which are vital competencies in modern scientific practice.

From a didactic perspective, the study highlights the transformative role of PBL in shifting the educational paradigm from teacher-centered to student-centered learning. The instructor's role evolves into that of a facilitator who guides students through inquiry, exploration, and reflection. This approach aligns with contemporary educational goals focused on competency-based learning and the development of functional scientific literacy.

The systematic implementation of problem-based approaches in teaching chromatographic methods is highly recommended. It not only increases the didactic value of the subject but also prepares students for professional challenges by equipping them with essential analytical and research skills. Future studies may focus on expanding this approach to other areas of analytical chemistry and exploring its long-term impact on students' academic and professional development.

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