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INTEGRATED METHODOLOGICAL GUIDE FOR ENHANCING RESEARCH COMPETENCE OF STUDENTS IN PHYSICAL METHODS OF CHEMICAL RESEARCH

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ABSTRACT

This study aimed to develop and evaluate an integrated methodological guide designed to enhance students' research skills in the Physical Methods of Chemical Research course. A Research and Development (R&D) approach combined with a quasi-experimental control-group design was employed. The study comprised four stages: development of the methodological guide, expert validation, practicality evaluation, and effectiveness testing. The guide integrated Inquiry-Based Learning (IBL), Problem-Based Learning (PBL), laboratory activities, and Bloom's Taxonomy-based multilevel tasks within a unified research-oriented learning framework. The study involved 112 third-year university students, of whom 50 were assigned to the experimental group and 62 to the control group. The experimental group was taught using the integrated methodological guide, whereas the control group received regular course instruction. Research skills were assessed across six indicators: interpretation, analysis, inference, evaluation, explanation, and self-regulation.

The findings supported the validity and practicality of the developed guide. The student practicality assessment reached 91.7%, and observed student activities reached 89.16%. The teacher practicality assessment was 77.9%, while observed teacher activities reached 90.12%. The experimental group demonstrated a high mean N-gain ($M = 0.7558$, $SD = 0.13940$), compared with a moderate mean N-gain in the control group ($M = 0.3887$, $SD = 0.20794$), indicating greater improvement in research skills among students who used the integrated methodological guide. Improvements were observed across all six research skill indicators, although the evaluation indicator showed comparatively lower improvement. In addition, 79.78% of student responses were classified in the good category. The findings indicate that the integrated methodological guide is a valid and practical instructional resource and that its implementation was associated with greater improvement in students' research skills compared with regular course instruction. The guide offers a structured approach to integrating theoretical knowledge, laboratory investigation, inquiry, problem solving, data analysis, scientific reasoning, and reflection in university chemistry education.

Keywords: Methodological guide; Research skills; Inquiry-based learning; Problem-based learning; Physical methods of chemical research; Chemistry education.

1 INTRODUCTION

The development of students' research skills is an important objective of contemporary higher education, particularly in science disciplines where learning requires not only the acquisition of the theoretical knowledge but also the ability to investigate scientific problems and work with experimental evidence [1]. In chemistry education, students are expected to interpret scientific information, analyze experimental data, draw evidence-based inferences, evaluate the reliability of results, provide scientifically grounded explanations, and reflect on their own reasoning and research decisions [2]. These skills are particularly important for university students because they enable learners to move beyond the reproduction of theoretical knowledge toward active participation in scientific inquiry and research-oriented problem solving [3].

The development of research skills is especially relevant in the Physical Methods of Chemical Research course [4]. The course introduces students to physicochemical methods of analysis and requires them to understand analytical principles, work with experimental procedures and instrumentation, process measurement results, interpret experimental data, and formulate scientifically justified conclusions [5]. However, learning such methods through predominantly theoretical instruction or p

redetermined laboratory procedures may provide limited opportunities for students to independently formulate problems, make methodological decisions, evaluate evidence, and reflect on the research process [6]. Therefore, instructional materials for this course should not only present theoretical content and laboratory procedures but also systematically engage students in research-oriented activities [7].

Active learning approaches provide an important pedagogical basis for addressing this need. Inquiry-Based Learning (IBL) encourages students to formulate questions, investigate problems, collect and interpret evidence, and construct explanations through inquiry [8]. Problem-Based Learning (PBL) engages learners in solving authentic and complex problems and supports the development of independent reasoning and problem-solving processes [9]. Laboratory activities provide opportunities to connect theoretical concepts with experimental evidence and scientific reasoning [10], while Bloom's Taxonomy-based multilevel tasks can progressively engage students in cognitive processes ranging from understanding and application to analysis and evaluation [11]. Together, these approaches can provide a structured learning environment in which students progressively engage in research-oriented activities and apply theoretical knowledge to experimental and problem-solving contexts.

Despite the growing use of inquiry-based, problem-based, and laboratory approaches in science education, limited attention has been given to their systematic integration with Bloom's Taxonomy-based multilevel tasks within a methodological guide specifically designed for the Physical Methods of Chemical Research course. In particular, there is a need for studies that examine the development of such a guide as a complete instructional product and evaluate it sequentially in terms of validity, practicality, and effectiveness, while also investigating changes across specific research skill indicators [12]. Addressing this gap can provide both methodological and empirical evidence for the design of research-oriented instructional materials in university chemistry education [13].

Therefore, this study developed an integrated methodological guide for the Physical Methods of Chemical Research course by combining Inquiry-Based Learning, Problem-Based Learning, laboratory activities, and Bloom's Taxonomy-based multilevel tasks. The developed guide was evaluated in three interconnected dimensions: validity, through expert assessment of its content and methodological structure; practicality, through student and teacher responses and observations of its implementation; and effectiveness, through comparison of changes in students' research skills between the experimental and control groups. Effectiveness was further examined across six research skill indicators: interpretation, analysis, inference, evaluation, explanation, and self-regulation. Student responses were also analyzed to complement the quantitative effectiveness results and provide insight into their experiences with the methodological guide [14].

Accordingly, the study addressed the following research questions:

RQ1. What content and structural components should be incorporated into an integrated methodological guide designed to develop students' research skills in the Physical Methods of Chemical Research course?

RQ2. To what extent is the developed integrated methodological guide valid and practical according to expert evaluation, student and teacher responses, and observations of its implementation?

RQ3. To what extent do changes in students' research skills differ between the experimental and control groups, particularly across the indicators of interpretation, analysis, inference, evaluation, explanation, and self-regulation?

2 MATERIALS AND METHODS

This study employed a Research and Development approach combined with a quasi-experimental design to develop and evaluate an integrated methodological guide for the Physical Methods of Chemical Research course. The study consisted of four main stages: development of the methodological guide, expert validation, practicality evaluation, and effectiveness testing.

The development stage focused on integrating Inquiry-Based Learning, Problem-Based Learning, laboratory activities, and Bloom's Taxonomy-based multilevel tasks into a unified methodological guide. Following its development, the guide was subjected to expert validation and

revised based on the recommendations obtained. Its practicality was subsequently evaluated through student and teacher responses and observations of the learning process. Finally, its effectiveness was examined using a quasi-experimental control-group design by comparing students' research skills between the experimental and control groups across six indicators—interpretation, analysis, inference, evaluation, explanation, and self-regulation—together with N-gain and student response data.

2.1 Development of the integrated methodological guide

The integrated methodological guide was developed in accordance with the content and learning outcomes of the Physical Methods of Chemical Research course. The guide integrates Inquiry-Based Learning (IBL), Problem-Based Learning (PBL), laboratory activities, and Bloom's Taxonomy-based multilevel tasks to provide students with structured opportunities to engage in research-oriented learning.

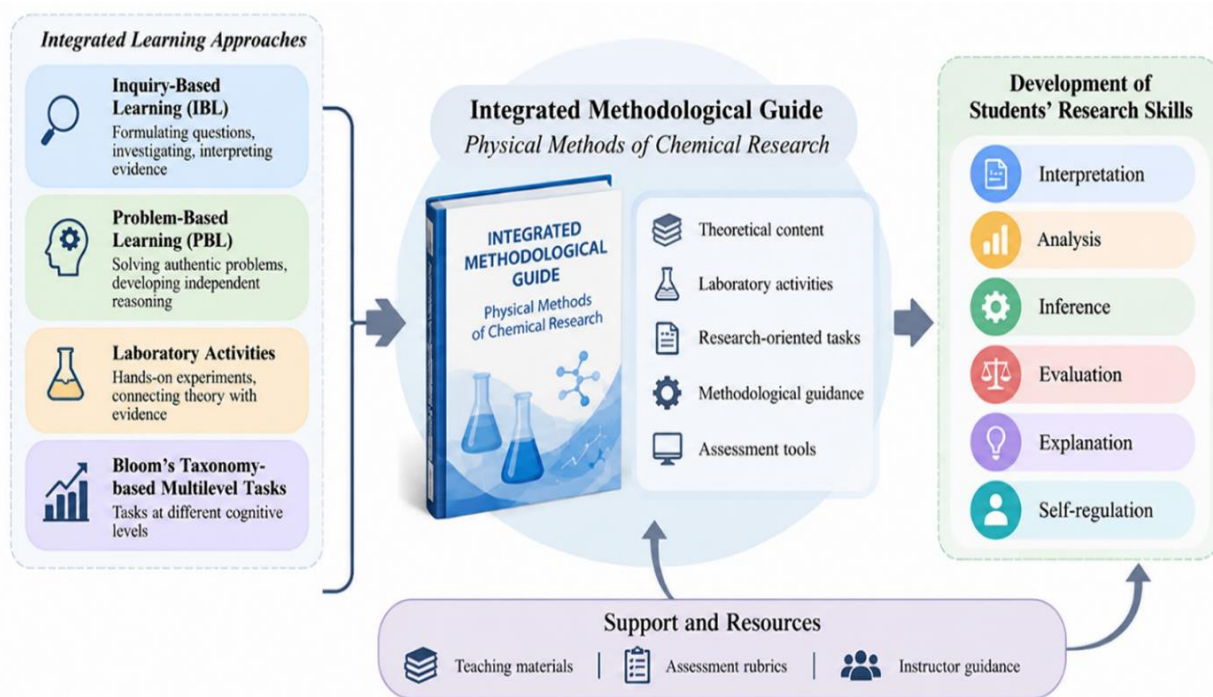


Figure 1 - Conceptual framework of the integrated methodological guide for developing students' research skills

The development of the guide was aimed at connecting theoretical knowledge with laboratory experimentation, research problem solving, analysis and interpretation of experimental data, evaluation of evidence, scientific explanation, and reflection. The overall framework for the development and evaluation of the integrated methodological guide is presented in Figure 1.

As illustrated in Figure 1, the integrated methodological guide combines Inquiry-Based Learning, Problem-Based Learning, laboratory activities, and Bloom's Taxonomy-based multilevel tasks within a unified research-oriented learning framework. These components are systematically incorporated into the course to support the development of six research skill indicators: interpretation, analysis, inference, evaluation, explanation, and self-regulation.

Integrated methodological guide was developed in accordance with the content and learning outcomes of the course and was designed to systematically enhance students' research skills [15]. The general characteristics of the methodological guide are presented in Table 1, its content structure and learning activities are shown in Table 2, and the integration of the six research skill indicators into the learning tasks is presented in Table 3.

Following the development of the methodological guide, its validity, practicality, and effectiveness were systematically evaluated [16]. Expert validation was conducted to assess the appropriateness of its content and methodological structure, practicality was examined through

questionnaires and observations during implementation, and effectiveness was evaluated by comparing research skill development between the experimental and control groups.

Table 1. General characteristics of the integrated methodological guide

Component	Description
Course	Physical Methods of Chemical Research
Target Group	Third-year university students
Purpose	To systematically develop students' research skills through integrated research-oriented learning activities
Instructional Approaches	Inquiry-Based Learning , Problem-Based Learning, laboratory activities, Bloom's Taxonomy-based multilevel tasks
Learning Organization	Integration of theoretical learning, research-oriented tasks, laboratory experimentation, data analysis, interpretation, evaluation, and reflection
Research Skill Indicators	Interpretation, analysis, inference, evaluation, explanation, and self-regulation
Evaluation of the Guide	Validity, practicality, and effectiveness

Table 2. Content structure and learning activities of the integrated methodological guide

Learning content	Description
Fundamentals of Physicochemical methods of analysis	(1) Studying the characteristics of physicochemical methods of analysis; (2) exploring the areas of application of physicochemical methods; (3) understanding the fundamental concepts and principles used in physicochemical analysis; (4) completing assessment tasks for the section.
Spectrophotometric methods of analysis	(1) Studying the theoretical foundations of spectrophotometric analysis; (2) exploring the structure and operating principles of the instruments used; (3) analyzing the areas of application of the method; (4) completing section-based tasks; (5) Laboratory Work No. 1: Spectrophotometric determination of Cu^{2+} ions in natural flowing water.
Atomic absorption spectroscopy	(1) Studying the theoretical foundations of atomic absorption spectroscopy; (2) exploring the operating principles of the instrument used; (3) analyzing the areas of application of the method; (4) completing assessment tasks; (5) Laboratory Work No. 2: Photometric determination of manganese and chromium in a mixture.
Infrared spectroscopy	(1) Studying the general principles of infrared spectroscopy; (2) exploring the characteristics and operating principles of the instruments used; (3) analyzing the areas of application of the method; (4) completing assessment tasks; (5) Laboratory Work No. 3: Spectrophotometric determination of caffeine using ultraviolet-visible (UV-Vis) spectroscopy.
Potentiometric methods of analysis	(1) Studying the theoretical foundations of potentiometric analysis; (2) exploring the instruments used and their operating principles; (3) analyzing the areas of application of the method; (4) completing assessment tasks; (5) Laboratory Work No. 4: Determination of the solubility product of a sparingly soluble salt using potentiometry.
Electrolysis and coulometric methods of analysis	(1) Studying the theoretical foundations of electrolysis and coulometry; (2) exploring coulometric instruments and their operating principles; (3) analyzing the areas of application of coulometric methods of analysis; (4) completing assessment tasks; (5) Laboratory Work No. 5: Determination of acid concentration by coulometric titration.

Table 3. Integration of research skill indicators into the learning tasks of the integrated methodological guide

Research skill indicator	Learning tasks
Interpretation	Interpret scientific and experimental information; identify relevant information in experimental data; interpret graphs, tables, spectra, and measurement results; relate experimental findings to physicochemical principles.
Analysis	Analyze research problems and experimental data; identify relationships among variables; compare experimental results; distinguish relevant and irrelevant evidence; relate obtained findings to theoretical principles.
Inference	Draw evidence-based inferences from experimental data; predict possible outcomes; formulate scientifically justified conclusions; determine whether the available evidence supports the proposed conclusion.
Evaluation	Evaluate the accuracy and reliability of experimental results; assess the appropriateness of the selected analytical method; identify possible sources of experimental error; evaluate the quality and limitations of evidence and research procedures.
Explanation	Explain experimental findings using appropriate scientific concepts; justify the selection of analytical methods and research procedures;

2.2 Participants and study context

The study involved 112 third-year students enrolled in the Physical Methods of Chemical Research course at Abai Kazakh National Pedagogical University during the 2025/2026 academic year. The participants were divided into two groups: an experimental group consisting of 50 students and a control group consisting of 62 students. The participants were assigned to the experimental and control conditions based on their existing academic groups; therefore, individual random assignment was not performed. The experimental group received instruction using the integrated methodological guide, whereas the control group followed regular course instruction. Students' research skills were assessed across six indicators: interpretation, analysis, inference, evaluation, explanation, and self-regulation.

2.3 Research methods

The Research Skills Test was administered to assess students' research skills and to evaluate changes associated with the implementation of the integrated methodological guide. The test consisted of 12 questions addressing six indicators based on Facione's framework: interpretation, analysis, inference, evaluation, explanation, and self-regulation. The assessment results were used to compare changes in research skills between the experimental and control groups.

Questionnaires were used to evaluate the validity, practicality, and implementation of the methodological guide. They included expert validation, student practicality, teacher practicality, and student response questionnaires using a five-point Likert scale, as summarized in Figure 2. Open-ended items were also included to obtain comments and recommendations for improving the guide.

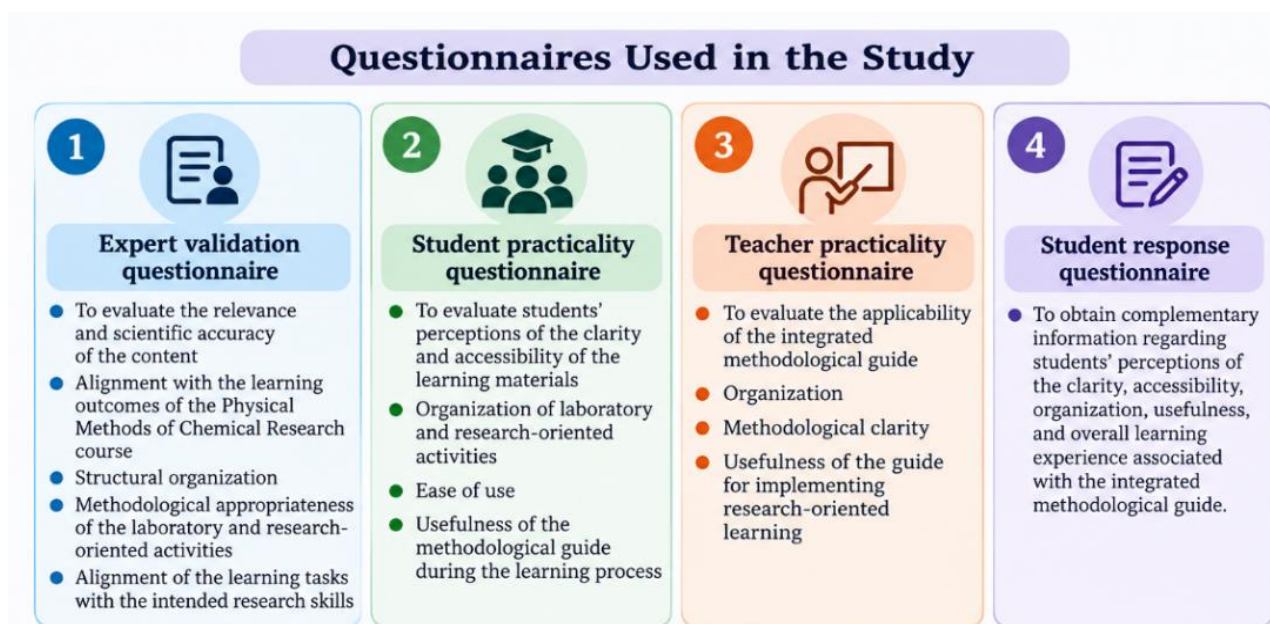


Figure 2 - Questionnaires Used for the Evaluation of the Integrated Methodological Guide

Semi-structured interviews were conducted to obtain qualitative data on students' experiences with the integrated methodological guide, including its clarity, usefulness, research-oriented activities, encountered difficulties, and suggestions for improvement [18]. Structured observations were used to evaluate the practicality and implementation of the methodological guide. Student observations focused on participation in laboratory, inquiry-based, problem-based, and research-oriented activities, while teacher observations assessed the organization and facilitation of learning activities and the support provided to students.

All research instruments were validated by experts in chemistry education, research methodology, and educational practice to ensure their clarity, relevance, and alignment with the study objectives. Particular attention was given to the alignment of the Research Skills Test with the six

indicators—interpretation, analysis, inference, evaluation, explanation, and self-regulation. The instruments were revised based on expert recommendations before implementation.

Quantitative and qualitative data were analyzed to evaluate the validity, practicality, and effectiveness of the integrated methodological guide. Quantitative data from expert validation, questionnaires, observations, and research skill assessments were analyzed using descriptive and inferential statistics. Qualitative data from interviews and open-ended responses were analyzed descriptively to complement the quantitative findings.

Product validity was evaluated using an expert validation questionnaire based on a five-point Likert scale, covering content relevance and scientific accuracy, alignment with course learning outcomes, structural organization, methodological appropriateness, and alignment with the intended research skills. Expert scores were converted into percentages, while comments and recommendations were used to revise the guide before implementation.

Product practicality was evaluated using student and teacher practicality questionnaires and structured observations of student and teacher activities. Questionnaire and observation scores were analyzed descriptively and converted into percentages to determine the practicality of the methodological guide during implementation.

Product effectiveness was evaluated by comparing the research skill assessment results of the experimental group and control group. The data were examined for normality, and inferential statistical analysis was used to determine whether there was a statistically significant difference in research skill development between the experimental and control groups.

Students' improvement was further analyzed using the normalized gain (N-gain). The analysis was conducted for the overall research skill score and for the six indicators: interpretation, analysis, inference, evaluation, explanation, and self-regulation. Scores for each indicator were also converted into percentages and classified into five research skill levels, as presented in Table 4.

The magnitude of the difference between the experimental group and control group was examined using Cohen's *d* effect size. Student response questionnaire data were analyzed descriptively and converted into percentages, while interview and open-ended responses were used to identify students' experiences, perceived benefits, difficulties, and suggestions for improvement.

Table 4. In order to determining students' research skill levels

Score (x)	Category
$0 \leq x \leq 43.75$	Very low
$43.75 < x \leq 62.50$	Low
$62.50 < x \leq 71.50$	Moderate
$71.50 < x \leq 81.25$	High
$81.25 < x \leq 100$	Very high

3 RESULTS AND DISCUSSION

This section presents and discusses the main findings of the study in four areas: (1) development of the integrated methodological guide, (2) product validity, (3) product practicality, and (4) product effectiveness. The results are presented systematically in the following subsections, with particular attention to the structure and implementation of the developed guide and its contribution to the development of students' research skills.

The development of the integrated methodological guide was motivated by the need for a more systematic approach to developing students' research skills within the Physical Methods of Chemical

The analysis conducted during the development stage indicated that conventional learning materials primarily focused on theoretical content, principles of analytical methods, instrumentation, and laboratory procedures, while opportunities for students to engage systematically in research-oriented activities were comparatively limited. In particular, there was a need to connect theoretical knowledge with problem identification, experimental planning, data analysis and interpretation, evidence-based reasoning, and scientific conclusions. The developed methodological guide covers the major topics of the Physical Methods of Chemical Research course, including physicochemical

methods of analysis, spectrophotometric methods, atomic absorption spectroscopy, infrared spectroscopy, potentiometric methods, electrolysis, and coulometric methods. Each section combines theoretical foundations with instrument-related content, practical applications, multilevel assessment tasks, and laboratory activities. Five laboratory works were incorporated into the guide to provide students with opportunities to apply theoretical knowledge to experimental and research-related problems.

Following the initial development stage, the methodological guide and related research instruments underwent expert validation and revision. Comments and recommendations provided by the experts were used to improve the content, structure, clarity, and methodological organization of the guide before its implementation. The final version was subsequently used in the Physical Methods of Chemical Research course, with the experimental group receiving instruction using the integrated methodological guide and the control group receiving regular course instruction. The practicality and effectiveness of the developed guide were then evaluated in relation to the development of students' research skills.

3.1 Product practicality

The student practicality questionnaire showed that the integrated methodological guide achieved a practicality score of 91.7%, categorized as very practical. Observations of students' activities during the learning process yielded a score of 89.16%, categorized as very good. These findings indicate that the methodological guide was highly practical and could be effectively implemented in the learning process.

The high practicality reported by students suggests that the guide was systematically organized, accessible, and supportive of research-oriented learning [19]. The integration of Inquiry-Based Learning, Problem-Based Learning, laboratory activities, and Bloom's Taxonomy-based multilevel tasks enabled students to engage actively in investigation, data analysis, interpretation, and reflection rather than merely following predetermined procedures. This is consistent with previous studies emphasizing the role of inquiry- and problem-based learning in promoting active investigation, problem solving, and knowledge construction.

Teacher evaluation provided additional evidence of the guide's practicality. The questionnaire completed by 12 chemistry teachers yielded a score of 77.9%, categorized as practical, while observations of teacher activities reached 90.12%, categorized as excellent. These findings indicate that the guide was applicable for organizing research-oriented learning and provided a structured connection between theoretical content, laboratory activities, and research tasks. Such alignment between learning objectives, instructional activities, and assessment contributes to a coherent learning environment.

Observations further showed that students actively participated in identifying research problems, conducting experiments, analyzing and interpreting data, evaluating results, and formulating scientific conclusions.

The practicality findings – 91.7% for student questionnaires, 89.16% for student activity observations, 77.9% for teacher questionnaires, and 90.12% for teacher activity observations—demonstrate that the integrated methodological guide was practical and feasible for implementation in the Physical Methods of Chemical Research course. Following the practicality evaluation, the effectiveness of the guide was examined by comparing the research skill development of the experimental and control groups across six indicators: interpretation, analysis, inference, evaluation, explanation, and self-regulation.

In line with these findings, further analysis was conducted to examine the development of research skills across the six indicators. The results revealed variations in the level of improvement across the indicators, with the experimental group demonstrating higher N-gain scores than the control group across all six indicators. Among the experimental group, the evaluation indicator showed comparatively lower improvement than the other research skill indicators. These results are presented in Figure 3.

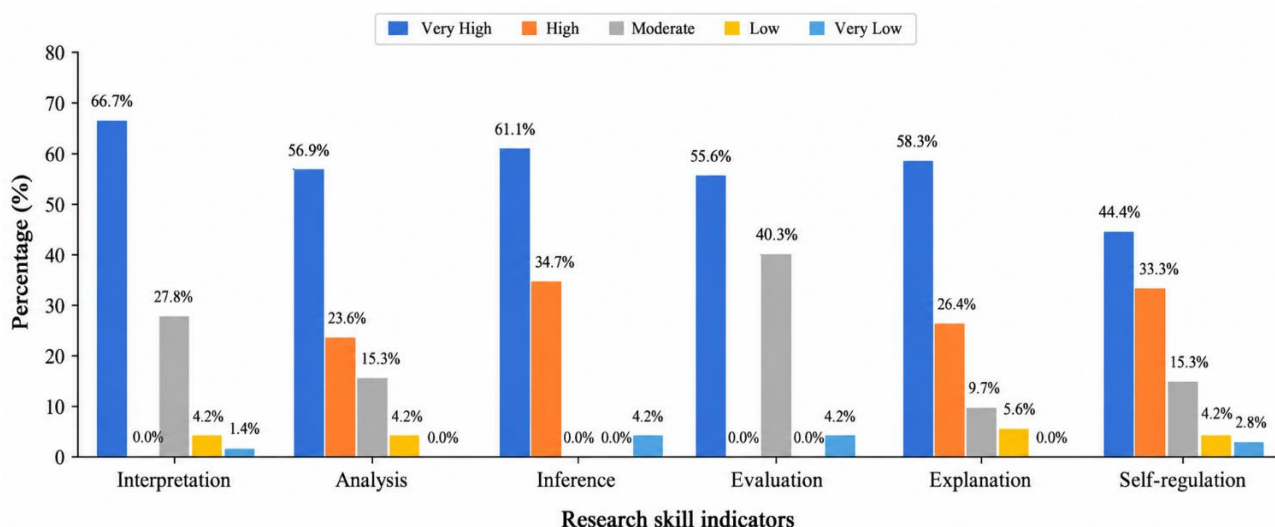


Figure 3 - Comparison of N-gain scores across research skill indicators between the experimental and control groups

Figure 4 presents the distribution of students across five research skill levels for each of the six indicators. The results show that a substantial proportion of students reached the very high level across the indicators, particularly in interpretation, inference, and explanation.

However, the distribution varied across the six indicators, indicating that the development of research skills was not uniform across all areas.

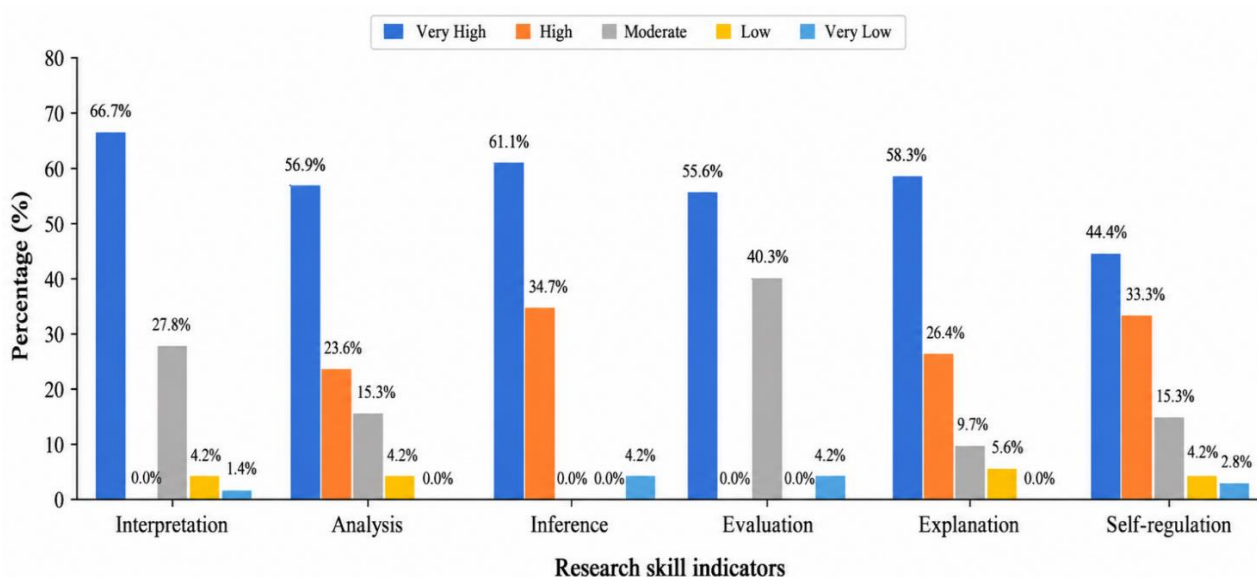


Figure 4 - Distribution of research skill levels across the six indicators

3.3 Results of the effectiveness test

The effectiveness analysis began with prerequisite statistical testing to determine the appropriateness of the data for further analysis. After the statistical assumptions were examined, comparative analyses were conducted to evaluate differences in research skill development between the experimental and control groups.

The results demonstrated greater improvement in research skills among students in the experimental group, who received instruction using the integrated methodological guide, compared

with those in the control group who received regular course instruction. The observed improvement was reflected across the six research skill indicators: interpretation, analysis, inference, evaluation, explanation, and self-regulation.

To determine the magnitude of improvement in students' research skills, normalized gain (N-gain) scores were calculated and compared between the experimental and control groups. The N-gain analysis provided a quantitative measure of the improvement achieved by each group and allowed the effectiveness of the integrated methodological guide to be evaluated relative to regular course instruction. The results of the N-gain analysis are presented in Table 5.

Table 5. Summary of N-gain values

Groups	M	SD	Description
Control group	0.3887	0.20794	Moderate
Experimental group	0.7558	0.13940	High

*Acronyms and abbreviations: *M* – Mean; *SD* – Standard deviation.

The effectiveness analysis showed that the experimental group achieved greater improvement in research skills than the control group. Positive changes were observed across all six research skill indicators: interpretation, analysis, inference, evaluation, explanation, and self-regulation [20]. Greater improvements were observed in interpretation, analysis, inference, explanation, and self-regulation, while the evaluation indicator showed comparatively lower improvement. Students experienced particular difficulties in evaluating experimental evidence, identifying potential sources of error, and justifying research decisions [21, 22].

The effect size analysis yielded a Cohen's *d* value of 2.07379, indicating a large effect and supporting the substantial difference in research skill development between the experimental and control groups. Together with the N-gain results, this finding supports the effectiveness of the integrated methodological guide in developing students' research skills.

Student responses also supported the implementation of the guide, with 79.78% of responses classified in the good category. Students positively evaluated its clarity, accessibility, organization, and usefulness and valued the integration of theoretical content, laboratory activities, and research-oriented tasks. However, some students reported difficulties with complex tasks involving the evaluation of experimental evidence and justification of research decisions.

The interview findings further showed that students considered the learning materials systematically organized and understandable and valued the connection between theoretical content, laboratory activities, and research-oriented tasks. Students particularly appreciated opportunities to participate actively in identifying research problems, conducting experiments, analyzing and interpreting data, and formulating scientific conclusions.

4 CONCLUSION

This study demonstrates that the developed integrated methodological guide is a valid, practical, and effective instructional resource for the course. The guide integrates Inquiry-Based Learning (IBL), Problem-Based Learning (PBL), laboratory activities, and Bloom's Taxonomy-based multilevel tasks within a unified framework to support research-oriented learning.

The practicality results showed positive evaluations from both students and teachers, with scores ranging from 77.9% to 91.7%. The effectiveness analysis showed that the experimental group achieved greater improvement in research skills than the control group, as reflected in the N-gain results and the large effect size (Cohen's *d* = 2.07379). Improvements were observed across all six research skill indicators, although the evaluation indicator showed comparatively lower improvement. Student responses were also positive, with 79.78% of responses classified in the good category.

Overall, the findings indicate that the integrated methodological guide effectively supports the development of students' research skills by connecting theoretical knowledge with laboratory investigation, inquiry, problem solving, data analysis, scientific reasoning, and reflection. The guide

therefore provides a structured approach to research-oriented learning in the Physical Methods of Chemical Research course.

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