European International Journal of Pedagogics

TYPE Original Research
PAGE NO. 199-204
DOI 10.55640/eijp-05-11-47

Check for updates

Enhancing Students' Practical Skills In Analytical Chemistry Through Problem-Based Learning

Jurayeva Barno Abdixalilovna

Assistant at the department of chemistry at the Tashkent Institute of Chemical Technology, Uzbekistan

OPEN ACCESS

SUBMITTED 12 October 2025
ACCEPTED 08 November 2025
PUBLISHED 30 November 2025
VOLUME Vol.05 Issue11 2025

Abstract: Analytical chemistry is an important part of undergraduate chemistry programs because it teaches students how to get accurate data that can be used to make decisions in research, business, and environmental monitoring. But traditional "recipe-style" lab instruction often produces students who can follow directions but have a hard time designing experiments, figuring out how to fix problems, or making sense of complicated datasets. Problem-based learning (PBL) provides a learner-centered approach that contextualizes laboratory techniques within genuine analytical challenges, necessitating the integration of theory, practice, and professional competencies. This article delineates a pedagogical framework for incorporating Project-Based Learning (PBL) into an undergraduate analytical chemistry curriculum, specifically aimed at augmenting students' practical competencies. A quasi-experimental design is delineated, contrasting a PBL-oriented laboratory sequence with a traditional verification-style laboratory over the course of one semester. Data sources comprise a rubric-based evaluation of manipulative skills and data management, performance on open-ended practical examinations, and student self-reports regarding confidence and autonomy. The results show that students in the PBL section are better at procedural fluency, recognizing mistakes, handling instruments, evaluating data, and working as a team than students in the traditional section. They also make at least the same amount of progress in understanding concepts. The discussion elucidates these findings in the context of recent studies on PBL in analytical chemistry laboratories, emphasizing the significance of scaffolding, the congruence between problems and techniques, and the explicit evaluation of practical skills. The article ends with useful tips for teachers who want to add PBL in stages, as well as ideas for more research on how to keep and transfer analytical lab skills over

time.

Keywords: Analytical chemistry education; problem-based learning; practical skills; laboratory teaching; higher education; student-centred learning.

Introduction: Analytical chemists' professional identity is based on their ability to work in a lab. Graduates must not only know how to use instruments and follow standard operating procedures, but they must also know how to come up with new methods, check the quality of results, and fix problems that come up when working with complicated samples or in tight spaces. However, a lot of undergraduate analytical chemistry labs still use experiments that are very structured and follow a recipe, where students get the same result by following step-by-step instructions. These kinds of labs may make sure that a certain number of techniques are covered, but they often don't teach students how to think critically, solve problems on their own, or make good experimental decisions. Research in chemistry education has consistently indicated that students who excel in conventional laboratories frequently encounter difficulties when faced with ambiguous problems or unfamiliar experimental settings.

Problem-based learning has come to light as a promising way to get around these problems. PBL, which started in medical education and has since spread to other fields, organizes lessons around difficult, open-ended problems that are similar to what professionals do in their jobs. In a PBL setting, students work in small groups to look at a problem, figure out what they need to learn, look into relevant theories and methods, and come up with and test experimental solutions. In analytical chemistry labs, this could mean coming up with a way to measure an analyte in a difficult matrix, comparing different ways to prepare a sample, or making sure that a calibration method works with the resources that are available. The teacher's job changes from giving out information about procedures to guiding questions, helping students think about what they've learned, and making sure that safety and scientific standards are followed.

There is more and more evidence in the literature that PBL can help students learn chemistry skills in a more meaningful way. Research on student-led PBL mini-projects shows that they increase confidence in the lab, attendance, and engagement, as well as a deeper understanding of how theory and practice are related. Studies on PBL in analytical chemistry courses have demonstrated beneficial outcomes on creative thinking, self-directed learning strategies, and problem-solving, frequently yielding learning advancements that exceed those found in conventional laboratory settings. Research in quantitative analytical chemistry indicates that PBL can facilitate students' transition from rote memorization to the strategic application of analytical techniques, especially when problems are structured to incorporate decision-making regarding sampling, calibration, and sources of error.

Still, it's not easy to add PBL to analytical chemistry labs. Teachers have to deal with limits on contact hours, safety, the cost of reagents and instrument access, and the school's expectations for content coverage and assessment. Students may initially resist tasks that are more open-ended, especially if they are used to experiments that are very structured and grades that are based on how well they do. Recent research underscores the significance of scaffolding Project-Based Learning (PBL) tasks, establishing explicit performance criteria, and aligning assessment with the cultivation of process skills rather than solely focusing on final outcomes. Additionally, there is a necessity for research that directly correlates PBL design decisions to quantifiable outcomes in practical skill enhancement, rather than solely to general attitudes or conceptual advancements.

In this context, the current article discusses the topic "Integration of Enhancing Students' Practical Skills in Analytical Chemistry Through Problem-Based Learning" by proposing and examining a model for incorporating PBL into a semester-long undergraduate analytical chemistry course. The emphasis is on the systematic integration of PBL to target essential practical skills, such as experimental planning, the safe and efficient management of reagents and instruments, real-time troubleshooting, data processing and interpretation, and collaborative communication within the laboratory. The research contrasts a PBL-oriented laboratory segment with a conventional verification-oriented segment, employing various metrics of practical performance and student perceptions. In this way, it hopes to give teachers both real-world evidence and useful advice on how to change analytical chemistry labs from places where students just follow instructions into places where they learn to think and act like new analytical chemists.

The study took place in a medium-sized university's second-year undergraduate analytical chemistry class. There was a three-hour lecture and a three-hour lab session each week for the course. The same teacher taught two parallel laboratory sections in the same semester. They both covered the same analytical topics, such as acid-base titrimetry, spectrophotometric analysis, chromatographic separation, and electroanalytical techniques. One section used a traditional verification-style lab format, and the other used a PBL-based format. The lecture, tests that weren't related to lab work, and final exam were all the same for both groups.

The sample consisted of seventy-two chemistry and allied majors who voluntarily enrolled in laboratory sections during registration. To minimize selection bias, students were merely informed that the two sections would employ distinct teaching methodologies, without indicating that one was based on PBL. After making changes to the drop-add, the traditional section had thirty-six students and the PBL section had thirty-four students. The groups had similar demographic traits and past performance in general chemistry, with no statistically significant differences in average grade point averages or previous lab experience.

In the conventional laboratory, each session focused on a designated experiment intended to demonstrate a specific analytical method. Students got a full manual that told them what the goals were, what the theory was, what the reagents were, how to set up the equipment, how to do each step, and how to handle the data. There were some small mistakes and changes that were okay, but there weren't many chances to change the experimental design or try out different methods. Formal reports stressed doing things right and getting the right numbers.

In the PBL lab, each two-week block was based on an analytical problem that was based on a real-life situation, like figuring out how much of a contaminant is in river water or comparing the amount of active ingredient in different pharmaceutical tablets. The problem description gave some background information, set limits on time and equipment, and said what level of quality the results had to be. However, it did not tell the researchers how to do the experiment. Students worked in groups of three or four to figure out what was wrong, remember what they had learned in class, and come up with ways to test their ideas, such as sampling, choosing a method, making calibration models, and figuring out where the uncertainty might come from. The instructor and a graduate teaching assistant led the groups through questioning and feedback instead of giving them direct instructions on how to do things. This made sure that the plans they came up with were safe and possible with the lab resources they had.

Multiple data sources were utilized to assess the influence of PBL on practical skills. At the beginning and end of the semester, students had to do a short titration or spectrophotometric determination under observation as part of a practical skills test. An analytic rubric that included preparation and safety, handling of equipment, carrying out procedures, recording data, processing data, and writing interpretive commentary was used to grade their work. Rubrics that focused on the clarity of the experimental rationale, the quality of the data analysis, and the reflection on limitations were also used to grade laboratory notebooks and group reports at the end of each block. Students also filled out a self-report questionnaire near the end of the semester about how confident and independent they felt in the lab, how they felt about the lab format, and how they thought they had improved their teamwork and communication skills. The questionnaire utilized a five-point Likert scale and featured open-ended questions.

Descriptive statistics and inferential tests, such as independent samples t-tests and effect size calculations, were used to look at quantitative data from rubric scores and questionnaires. These tests were chosen based on the approximate nature of the data. Thematic analysis was conducted on qualitative responses from open-ended questions and instructor field notes to discern patterns in students' experiences of the two laboratory formats. The study is confined to a singular institutional context and does not assert extensive generalizability; however, the mixed-method approach offers a comprehensive insight into the impact of integrating PBL on the development of practical skills in analytical chemistry.

At the start of the semester, the pre-test scores on the practical skills assessment showed that the groups were about the same level, and there was no statistically significant difference in the total rubric scores. Students in both laboratory formats demonstrated a fundamental understanding of standard glassware and basic titration techniques; however, their capacity to rationalize procedural decisions and evaluate data quality was constrained. The post-test results showed a clear difference in performance by the end of the semester. Students in the PBL section had higher average scores on the overall rubric and in almost all of the sub-dimensions. This was especially true for handling apparatus, recording data, processing data, and writing interpretive commentary. The most noticeable difference was in the interpretive commentary dimension, where PBL students were more likely to explain why things went wrong, think about how experimental mistakes affected the final results, and suggest specific ways to make things better.

In the traditional section, the main improvements were in how well tasks were done and how quickly they were finished. These students got better at following written instructions and were more accurate when they were in familiar situations, but they were less likely to question instructions or look for other ways to do things. In the post-test, when faced with a slightly altered procedure or an unfamiliar source of interference, numerous traditional-section students resorted to guessing or sought additional assistance, suggesting that their procedural fluency was closely linked to the specific manual they had previously utilized.

Examination of laboratory notebooks and collective reports corroborated these findings. PBL groups gradually provided more coherent rationales for their experimental designs, explicitly citing analytical figures of merit such as sensitivity, selectivity, and detection limit. They recorded choices about calibration ranges, sample volumes, and instrument settings in a way that showed they were starting to understand how to develop methods. Their data analysis sections often had short talks about outliers, systematic deviations, and uncertainty. Their reflections talked about the limits of their method and suggested possible follow-up experiments. In contrast, traditional-section notebooks were usually well-organized when it came to writing down steps and numbers, but the reasons for choices were rarely explained beyond saying that a certain method was assigned or commonly used.

Self-reported questionnaire data indicated variations in students' perceived confidence and autonomy. PBL students said they were more confident in planning experiments, dealing with unexpected results, and using tools on their own. They often said that the open-ended problems were hard or uncomfortable at first, but they eventually became interesting and made them pay more attention to the basic ideas and use the course materials more. Students in the traditional section said they liked how clear and safe structured manuals were, but they weren't as sure they could design an experiment from scratch or change a procedure to fit a new situation.

Open-ended responses also showed how important group work and communication are. A lot of PBL students said that working together to talk things out was the most important part of coming up with experimental strategies and settling disagreements about how to interpret data. Participants recounted their experiences in learning to allocate tasks, verify each other's measurements, and collaboratively author reports in a manner akin to professional analytical teams. Group work did happen in the traditional section, but it was mostly just sharing tools and splitting up regular tasks instead of working together to come up with the experimental design. Instructor field notes confirmed the perception that the PBL laboratory environment was more dialogic, as students engaged with the instructor to discuss options and reflect on outcomes, in contrast to the traditional laboratory, which featured more inquiries for procedural clarification or verification of numerical responses.

In general, adding PBL to the analytical chemistry lab seems to have changed what students do from repeating known experiments to solving analytical problems that need planning, reasoning, and critical thinking. The quantitative and qualitative data, when considered collectively, indicate that this transition facilitates the enhancement of more comprehensive and transferable practical skills without undermining fundamental procedural proficiency.

This study's results are in line with and build on earlier work that shows how PBL can help students develop higher-order skills in chemistry labs. Research on PBL mini-projects indicates that when students assume responsibility for the planning and execution of their experimental protocols, they cultivate a more genuine understanding of the practical application of chemistry and exhibit increased engagement and satisfaction. The current findings contribute to the existing literature by concentrating on analytical chemistry and by recording improvements in observable practical skills through a structured rubric that differentiates between manipulative, cognitive, and interpretive dimensions.

One of the most significant results is that students in the PBL section are better able to understand data and think about how good their experiments are. This is similar to what was found in analytical chemistry labs, where students in PBL settings became better at self-regulated learning, creative thinking, and self-evaluation. This made them see lab tasks as problems to be solved instead of recipes to be followed. When PBL tasks are intentionally designed with ambiguous or noisy data, they implicitly instruct students to anticipate variability and to regard discrepancies as opportunities for investigation rather than mere errors to be concealed. In this study, PBL problems necessitated that students interpret results considering sample matrices, interferences, and limitations on method sensitivity, which seemingly enhanced their interpretive abilities.

The differences seen in laboratory notebooks and reports show how important clear justification is for improving professional analytical thinking. In PBL tasks, students had to say why they chose a certain way to analyze data, calibrate, or prepare a sample. This process is similar to the reasoning that is expected in published analytical methods, where authors have to explain why they chose certain methods and talk about how they affect accuracy, precision, and robustness. Research on PBL in quantitative analytical chemistry indicates that this approach can assist students in synthesizing diverse concepts, including acid-base equilibria, the Beer-Lambert law, and chromatographic selectivity, into cohesive decision-making frameworks. The present study corroborates this perspective by illustrating that, throughout a semester, PBL students progressively expressed their design decisions using analytical figures of merit.

The results also show how important scaffolding is for integrating PBL. Earlier studies have warned that students may become overwhelmed and go back to shallow strategies if problems are too open-ended or if there isn't enough guidance. In the course outlined here, scaffolding included structured problem descriptions, intermediate checkpoints for reviewing plans, and rubrics that made clear what was expected of both the process and the product. The teacher's role was more about asking questions and giving feedback than giving instructions. This balance between freedom and guidance seems to have been important in letting students run their own experiments without putting safety or feasibility at risk.

Another aspect is the growth of skills in working together and talking to others. In professional settings, analytical chemistry is not usually done alone. Laboratory teams need to work together to plan tasks, share data, and solve problems. The PBL environment naturally foregrounded these competences, as groups had to negotiate experimental designs and co-author reports. Students said they were more confident working in groups and that they learned from their peers' points of view on both theoretical and practical issues, which is in line with research on cooperative PBL labs. The traditional laboratory included group work, but its more rigid structure made it harder for people to make decisions together.

The study does have limitations. The quasi-experimental design, reliance on a single instructor and single institution, and moderate sample size constrain the generalisability of the results. Students enrolled themselves in sections, which may have led to slight differences in motivation or scheduling constraints, despite attempts to reduce bias. Rubric-based assessment, though systematically applied, still involves subjective judgement, and self-report questionnaires are vulnerable to social desirability effects. Future research could address these limitations by adopting multi-institutional designs, longitudinal follow-ups that track the retention and transfer of practical skills, and triangulation with external measures such as performance in industrial internships or research projects.

Despite these limitations, the study suggests that thoughtful integration of PBL into analytical chemistry laboratories can substantially enhance students' practical skills. It also illustrates that such integration does not require abandoning core analytical content or dramatically expanding contact hours. Instead, it involves reframing existing techniques and topics as components of meaningful problems, redesigning assessment to capture process skills and interpretive abilities, and adopting a facilitative teaching stance that trusts students to take responsibility for their learning.

The integration of problem-based learning into undergraduate analytical chemistry laboratories offers a powerful strategy for enhancing students' practical skills. By situating techniques within authentic analytical problems and requiring students to design, justify and evaluate their experimental approaches, PBL encourages the development of procedural fluency, experimental judgement, data literacy and collaborative competence. The study presented in this article demonstrates that students in a PBL-oriented analytical chemistry laboratory not only attain superior performance on rubric-based practical assessments but also express increased confidence and autonomy in the planning and execution of experiments, in contrast to their counterparts in a conventional verification-style laboratory.

These results highlight the necessity to reevaluate the function of the analytical chemistry laboratory within the curriculum. Rather than serving primarily as a site for verifying lecture content, the laboratory can become a space where students participate in simplified forms of authentic analytical practice. PBL offers a coherent structure for participation by conceptualizing each laboratory cycle as a problem necessitating continuous inquiry, knowledge integration, and reflective assessment. With appropriate scaffolding and clear assessment criteria, PBL can be implemented without jeopardising safety or content coverage.

For instructors and curriculum designers, practical steps include gradually replacing highly scripted experiments with problem-centred tasks, redesigning manuals to emphasise problem contexts and decision points, and using rubrics that assess planning, execution and interpretation alongside numerical accuracy. Professional development, resource allocation, and recognition of innovative teaching can all help make this transition easier. Future work should explore how PBL-based analytical laboratories influence students' performance in subsequent research experiences, industrial placements and postgraduate study, and how digital tools, such as virtual laboratories and data analysis platforms, can be integrated with PBL to further enrich practical skill development.

REFERENCES

1. Larive C. K. Problem-based learning in the analytical

chemistry laboratory course // Analytical and Bioanalytical Chemistry. – 2004. – Vol. 380. – P. 357–359.

2. McDonnell C., O'Connor C., Seery M. K. Developing practical chemistry skills by means of student-driven problem based learning mini-projects // Chemistry Education Research and Practice. – 2007. – Vol. 8, No. 2. – P. 130–139.
3. Yoon H., Woo A. J., Treagust D., Chandrasegaran A. L. The efficacy of problem-based learning in an analytical laboratory course for pre-service chemistry teachers // International Journal of Science Education. – 2014. – Vol. 36, No. 1. – P. 79–102.
4. Fitri N. Problem-Based Learning on Quantitative Analytical Chemistry // AIP Conference Proceedings. – 2017. – Article 020028.
5. Ram P. Problem-Based Learning in Undergraduate Instruction. A Sophomore Chemistry Laboratory // Journal of Chemical Education. – 1999. – Vol. 76. – P. 1122–1126.
6. Arsyad M., Guna S., Barus S. Enhancing chemistry education through problem-based learning: analyzing student engagement, motivation, and critical thinking // International Journal of Curriculum Development, Teaching and Learning Innovation. – 2024.
7. Varadarajan S., Ladage S. Exploring the role of scaffolds in problem-based learning in an undergraduate chemistry laboratory // Chemistry Education Research and Practice. – 2022.
8. Leite L., Dourado L., Morgado S. (eds.). Problem-Based Learning in Science Education: Achievements, Pitfalls and Ways Forward. – Basel: MDPI, 2024.
9. Reid N., Shah I. The role of laboratory work in university chemistry // Chemistry Education Research and Practice. – 2007. – Vol. 8, No. 2. – P. 172–185.
10. Barrows H. S. A taxonomy of problem-based learning methods // Medical Education. – 1986. – Vol. 20, No. 6. – P. 481–486.