

RESEARCH ARTICLE

Developing Students' Critical Thinking Skills Through Problem-Based Learning Technologies: The Case of Chemistry Education

Dilnoza Shukhrat qizi Elmurodova

Senior Lecturer, University of Economics and Pedagogy, Uzbekistan

VOLUME: Vol.06 Issue06 2026

PAGE: 65-69

Copyright © 2026 Journal of Social Sciences and Humanities Research Fundamentals, this is an open-access article distributed under the terms of the Creative Commons Attribution-Noncommercial-Share Alike 4.0 International License. Licensed under Creative Commons License a Creative Commons Attribution 4.0 International License.

Abstract

The development of students' critical thinking has become one of the major priorities of contemporary higher education, particularly in disciplines that require analytical reasoning, evidence-based decision-making, and the interpretation of complex phenomena. Chemistry education provides considerable opportunities for developing such competencies because the discipline is inherently associated with problem solving, hypothesis formulation, experimental investigation, interpretation of empirical evidence, and evaluation of alternative explanations. However, conventional teacher-centred approaches to chemistry instruction may limit students' active cognitive engagement and reduce learning to the reproduction of theoretical information and algorithmic problem-solving procedures. This study examines the pedagogical potential of problem-based learning (PBL) technologies for developing university students' critical thinking skills in chemistry education.

KEY WORDS

Critical thinking, problem-based learning, chemistry education, higher-order thinking, university students, scientific reasoning, problem-solving, inquiry-based learning, pedagogical technology, chemistry teaching.

INTRODUCTION

The transformation of higher education under the influence of scientific, technological, economic, and social changes has significantly altered expectations concerning the competencies that university graduates should possess. In contemporary educational environments, the ability to memorise and reproduce subject-specific information is no longer sufficient to ensure students' academic and professional success. Graduates are increasingly expected to analyse information critically, identify reliable evidence, formulate reasoned judgments, solve non-standard problems, evaluate alternative perspectives, and make scientifically justified decisions.

Among these competencies, critical thinking occupies a particularly important position. Critical thinking enables learners not simply to acquire information but to examine its

validity, determine relationships between evidence and conclusions, identify assumptions, recognise contradictions, and construct logically justified arguments. In science education, these abilities acquire additional significance because scientific knowledge is constructed and evaluated through evidence, observation, experimentation, interpretation, and argumentation.

Chemistry is one of the disciplines in which the development of critical thinking can be particularly productive. Chemical phenomena frequently have multiple explanatory levels: macroscopic observations, microscopic particle interactions, and symbolic representations. Students are required to establish relationships between these levels, interpret experimental observations, predict chemical transformations,

analyse quantitative data, and explain why a particular reaction occurs under specific conditions.

Nevertheless, traditional approaches to chemistry teaching often concentrate on the transmission of theoretical information and the reproduction of established solution algorithms. Such an approach can result in a situation in which students successfully solve standard textbook exercises but experience considerable difficulties when confronted with unfamiliar chemical problems. The discrepancy between procedural competence and conceptual reasoning indicates the necessity of methodological approaches that actively involve students in cognitive inquiry.

This distinction is particularly important for critical thinking. If the learner is given an algorithm in advance, cognitive activity can become primarily procedural. If the learner must determine which concepts, principles, data, or experimental procedures are relevant, the learning process requires significantly greater cognitive engagement.

Problem-Based Learning in Chemistry Education

Chemistry offers numerous opportunities for problem-based learning because many chemical questions can be formulated as authentic or semi-authentic scientific problems.

For example, instead of asking students to memorise factors affecting reaction rate, an instructor may present the following situation:

Two groups of students perform the same chemical reaction. The first group reports that the reaction proceeds rapidly, whereas the second group observes a significantly slower process. Both groups claim to have followed the same experimental procedure. What factors could explain the discrepancy, and what evidence would be required to determine the most plausible explanation?

Such a problem does not have to be solved by recalling a single fact. Students must:

1. identify potentially relevant variables;
2. distinguish independent and dependent variables;
3. formulate competing hypotheses;
4. determine what evidence would discriminate between hypotheses;
5. design or propose an investigation;
6. interpret possible results;

7. formulate a justified conclusion.

The cognitive structure of the activity corresponds closely to the components of critical thinking.

Another example can be drawn from acid-base chemistry. Rather than simply asking students to calculate pH, an instructor may pose the following problem:

Three aqueous solutions have approximately the same measured pH, but their resistance to the addition of a small amount of acid is substantially different. How can this observation be explained?

METHODOLOGY

The methodological framework proposed in this study is based on a combination of problem-based learning, inquiry-oriented instruction, collaborative learning, scientific argumentation, and reflective practice.

The implementation of the proposed model can be organised into six interconnected stages.

Stage 1. Diagnostic stage

At the initial stage, the instructor determines students' existing conceptual knowledge and critical-thinking abilities.

Diagnostic tasks should not be limited to factual questions. They should include open-ended problems requiring students to: explain their reasoning; identify assumptions; compare alternative explanations; evaluate evidence; justify conclusions.

This stage provides a baseline for determining students' cognitive needs.

Stage 2. Problem-orientation stage

The instructor introduces a scientifically meaningful problem situation.

An effective problem should possess several characteristics:

- it should be understandable but intellectually challenging;
- it should be connected with students' existing knowledge;
- it should allow more than one initial hypothesis;
- it should require evidence-based reasoning;
- it should create a meaningful contradiction or uncertainty;

- it should lead students toward new conceptual knowledge.

The quality of the problem situation is one of the decisive factors influencing the effectiveness of PBL.

Stage 3. Investigative stage

Students identify what they already know and what they need to determine. They formulate hypotheses and search for relevant theoretical or empirical information.

At this stage, the teacher should avoid immediately providing the correct explanation. Instead, the instructor functions primarily as a facilitator who asks questions such as:

- What evidence supports your assumption?
- Are there alternative explanations?
- Which variable may influence the observed result?
- How could you test this hypothesis?
- What information is still missing?
- What would constitute evidence against your proposed explanation?

Such questions stimulate metacognitive monitoring and make students more aware of the structure of their reasoning.

Stage 4. Evidence-analysis and argumentation stage

This stage is particularly important for the development of critical thinking.

Students compare experimental data, theoretical information, calculations, or observations and determine whether the available evidence supports their hypotheses.

A useful argumentative structure can be represented as:

Claim → Evidence → Reasoning → Counterargument → Revised conclusion.

For example, students may claim that temperature is the principal factor responsible for a difference in reaction rate. They then need to identify experimental evidence supporting the claim, explain the chemical mechanism, consider other possible factors, and determine whether the evidence is sufficient.

This process transforms chemistry learning into scientific reasoning rather than simple answer production.

Stage 5. Reflective stage

After solving the problem, students analyse the process through which they arrived at their conclusions.

Reflection may involve questions such as:

- What assumption did we make initially?
- Which evidence changed our interpretation?
- Which hypothesis was rejected and why?
- What error in reasoning could have affected our conclusion?
- What additional experiment would provide stronger evidence?
- How confident are we in our conclusion?

Reflection is important because critical thinking includes not only evaluating external information but also monitoring one's own cognitive processes.

Stage 6. Evaluation stage

Assessment should correspond to the objectives of critical-thinking development.

Therefore, instead of evaluating only the final answer, the teacher should assess:

- identification of the problem;
- quality of analysis;
- relevance and reliability of evidence;
- logical coherence of reasoning;
- consideration of alternatives;
- scientific justification;
- ability to revise an initial conclusion;
- quality of reflection.

A rubric-based approach can make such assessment more transparent and consistent.

RESULTS

The theoretical and methodological analysis conducted in this study indicates that problem-based learning possesses substantial potential for the development of critical-thinking competencies in chemistry education.

The proposed model establishes a direct relationship between chemistry-specific learning activities and the cognitive components of critical thinking.

PBL activity	Critical-thinking component	Chemistry context
Identifying the central problem	Analysis	Reaction mechanisms
Formulating hypotheses	Inference	Chemical equilibrium
Comparing explanations	Evaluation	Acid-base processes
Interpreting experimental data	Interpretation	Reaction kinetics
Defending a conclusion	Explanation	Analytical chemistry
Revising an initial hypothesis	Self-regulation	Experimental investigation

The analysis further suggests that the effectiveness of PBL is associated with a shift in the nature of students' cognitive activity. In teacher-centred instruction, students frequently concentrate on obtaining a correct answer. In problem-based environments, however, the emphasis moves toward why a particular answer is justified and what evidence supports it.

This distinction has significant pedagogical implications.

First, PBL creates conditions for the integration of theoretical and practical knowledge. Students do not perceive chemical concepts as isolated formulas or definitions; instead, they use them as intellectual tools for explaining phenomena.

Second, problem situations encourage students to tolerate cognitive uncertainty. In traditional instruction, uncertainty can be perceived as a problem that the teacher should immediately resolve. In PBL, uncertainty becomes a productive component of scientific inquiry.

DISCUSSION

The results of the theoretical analysis demonstrate that problem-based learning should not be interpreted merely as an instructional technique for increasing student activity. Its methodological significance is considerably broader.

The central contribution of PBL to critical-thinking development lies in the restructuring of the learning process around intellectually meaningful uncertainty.

In conventional chemistry instruction, the sequence is often:

theory → example → algorithm → exercise → answer.

In a problem-based environment, the sequence becomes:

problem → uncertainty → hypothesis → inquiry →

evidence → argument → conclusion → reflection.

The second sequence is cognitively more demanding because it requires students to make decisions concerning the direction of their own learning.

An important implication is that not every problem automatically develops critical thinking. A highly complicated calculation may still involve relatively low-level cognitive activity if students simply apply a known algorithm. Conversely, a comparatively simple problem can promote advanced reasoning if students must evaluate evidence and justify competing explanations.

For this reason, the pedagogical design of the problem is more important than its apparent complexity.

An effective chemistry problem should contain an element of epistemic uncertainty. Students should not be able to obtain the answer simply by recalling a definition. They should need to determine which knowledge is relevant, what evidence is needed, and how alternative explanations should be evaluated.

REFERENCES

1. Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn? *Educational Psychology Review*, 16(3), 235–266. <https://doi.org/10.1023/B:EDPR.0000034022.16470.f3>
2. Barrows, H. S. (1996). Problem-based learning in medicine and beyond: A brief overview. *New Directions for Teaching and Learning*, 1996(68), 3–12.
3. Savery, J. R. (2006). Overview of problem-based learning: Definitions and distinctions. *Interdisciplinary*

Journal of Problem-Based Learning, 1(1), 9–20.

4. Schmidt, H. G., Rotgans, J. I., & Yew, E. H. J. (2011). The process of problem-based learning: What works and why. *Medical Education*, 45(8), 792–806.
5. Miterianifa, Ashadi, Saputro, S., & Suciati, S. (2020). A conceptual framework for empowering students' critical thinking through problem-based learning in chemistry. *Journal of Physics: Conference Series*, 1–9.
6. Rusmansyah, Yanti, H., Saadi, P., Mahdian, Rusmanayanti, A., & Kusuma, A. E. (2025). Literature review: Application of the problem-based learning (PBL) model to critical thinking skills in chemistry learning materials. *Journal of Mathematics, Science and Computer Education*, 5(1), 43–52.
7. Nurpialawati, I., & Salirawati, D. (2026). A systematic literature review of problem-based learning in chemistry education: Advancing critical thinking and motivation. *Jambura Journal of Educational Chemistry*, 8(2), 267–278. <https://doi.org/10.37905/jjec.v8i2.40137>
8. Al-Zahra, N., & Muslim, B. (2026). The effect of the problem based learning model on critical thinking in basic chemical laws. *Journal of Educational Sciences*, 10(8), 497–515.
9. Mukni'ah. (2026). Problem-based learning in chemistry education: Its impact on university students' critical thinking skills in Indonesia. *Indonesian Journal of Education (INJOE)*, 5(3).
10. Dolmans, D. H. J. M., Wolfhagen, I. H. A. P., Van Der Vleuten, C. P. M., & Wijnen, W. H. F. W. (2001). Solving problems with group work in problem-based learning: Hold on to the philosophy. *Medical Education*, 35(9), 884–889.