

Developing Creative Competence in Chemistry Education Through International Assessment Tasks

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Abstract. This study examined an international assessment-based methodology for developing creative competence in academic-lyceum chemistry education. A 2023-2026 quasi-experiment involved 744 students from three Uzbek academic lyceums: 374 in experimental groups and 370 in control groups. The intervention combined PISA creative-thinking tasks, TIMSS knowing-applying-reasoning tasks, graph problems, contextual cases, experimental projects, STEAM activities, digital resources, and open-ended problem solving. Creative competence was assessed through divergent thinking, scientific transfer, originality, and scientific justification, operationalised with a rubric-based level scale. Final excellent/good performance reached 80.5% in experimental groups and 55.9% in controls. Recalculation from the raw four-level contingency table showed a significant pooled effect, $\chi^2(3, N = 744) = 72.565$, $p < .001$, Cramér's $V = .312$. Site-level tests were also significant, although low expected counts in unsatisfactory cells required a merged-category sensitivity check. The findings support the effectiveness of the integrated methodology, while component-specific effects require future dismantling studies.

Keywords: Academic Lyceum, Chemistry Education, Creative Competence, International Assessment, PISA and TIMSS.

1 Introduction

The rapid development of science, technology, industry, and digital communication has increased the need for learners who can think independently, generate original ideas, analyse complex problems, and apply knowledge in unfamiliar situations. In contemporary education, creativity is no longer considered an optional personal quality; rather, it is recognised as an essential competence for participation in scientific, technological, social, and professional life. Chemistry education has a particularly important role in this process because it combines abstract scientific concepts, experimental inquiry, modelling, data interpretation, and the solution of practical problems related to materials, health, energy, industry, and the environment.

Creative competence in chemistry education may be defined as a learner's capacity to identify a scientific problem, formulate alternative hypotheses, generate multiple solutions, select an original and feasible option, justify ideas by means of chemical laws and concepts, and improve a proposed solution through reflection. This competence includes divergent thinking, scientific transfer, originality, analytical reasoning,

experimental design, and scientific argumentation. It is especially relevant for academic lyceum students, whose learning should prepare them for higher education, scientific inquiry, and professional orientation in science-related fields.

International assessment programmes provide a productive methodological basis for developing such competence. The PISA creative-thinking framework focuses on students' ability to generate diverse and original ideas and to evaluate and improve ideas in open-ended contexts [1]. PISA assesses creative thinking through written expression, visual expression, social problem solving, and scientific problem solving. In contrast, TIMSS science assessment frameworks organise cognitive performance through the domains of knowing, applying, and reasoning [2]. These approaches are complementary for chemistry education: PISA-oriented tasks promote originality and idea development, while TIMSS-oriented tasks strengthen conceptual understanding, application, and scientific reasoning.

Current research highlights the value of interdisciplinary, problem-based, project-based, and STEAM-oriented learning for the development of students' creativity. Aguilera and Ortiz-Revilla [3] concluded that STEM and STEAM interventions can support the development of student creativity when tasks require active design, investigation, and problem solving. Guo et al. [4] found that project-based learning can strengthen cognitive, affective, and collaborative outcomes when students work on authentic problems. In chemistry education, contextual projects and design-thinking activities have also been shown to promote students' scientific reasoning, reflection, and problem-solving abilities [5], [6].

However, a major methodological problem remains. In many chemistry classrooms, students are expected mainly to reproduce definitions, formulas, reaction equations, and standard solution procedures. Such instruction may strengthen factual knowledge but does not consistently develop students' ability to use chemical knowledge creatively in real-life contexts. Students often experience difficulties in interpreting graphs, explaining experimental observations, designing investigations, comparing alternative solutions, or proposing innovative applications of chemical concepts.

The analysis of the dissertation materials showed that academic lyceum students initially relied primarily on reproductive knowledge. They had limited experience in generating independent solutions to non-standard chemical situations, planning experiments, interpreting graphical information, or justifying their ideas with scientific evidence. Therefore, chemistry teaching requires a methodical system that combines international assessment tasks with creative, contextual, inquiry-based, and practice-oriented activities.

The scientific novelty of this study lies in the integration of PISA creative-thinking tasks and TIMSS-oriented chemistry tasks into a structured methodology for developing creative competence among academic lyceum students. The methodology combines graph-based tasks with differentiated complexity, contextual chemical problems, case studies, experimental projects, digital resources, STEAM activities, and Bloom taxonomy-based cognitive progression.

The research question was formulated as follows: how does the systematic use of international assessment-based tasks influence academic lyceum students' creative competence in chemistry education?

The study was guided by the following hypothesis: if chemistry instruction is organised through PISA and TIMSS-oriented contextual, analytical, experimental, and open-ended tasks, then students' creative competence will improve significantly because they will be required to generate, evaluate, justify, and refine ideas while applying chemical knowledge to real situations.

The purpose of the study was to determine the effectiveness of using international assessment-based tasks for developing academic lyceum students' creative competence in chemistry education.

2 Methods

2.1 Research Design

The study employed a quasi-experimental design with parallel experimental and control groups. The pedagogical experiment was conducted during the 2023–2026 academic years and consisted of four interrelated stages:

1. organisational-preparatory stage;
2. diagnostic stage;
3. formative stage;
4. final analytical stage.

The organisational-preparatory stage aimed to establish the scientific, methodological, organisational, and diagnostic conditions necessary for the intervention. At this stage, the structure of creative competence was clarified, international assessment tasks were analysed, instructional materials were prepared, and assessment criteria were developed.

The diagnostic stage aimed to identify students' initial levels of creative competence. The students' ability to understand a problem, formulate a hypothesis, generate non-standard solutions, apply chemical concepts, interpret data, and provide scientific justification was evaluated.

The formative stage involved the systematic implementation of the developed methodology in experimental groups. Chemistry lessons were organised through PISA and TIMSS-oriented contextual tasks, graphical problems, open-ended questions, research assignments, laboratory projects, case studies, modelling tasks, and STEAM activities.

The final analytical stage focused on comparing the results of the experimental and control groups through four achievement levels: excellent, good, satisfactory, and unsatisfactory.

2.2 Participants and Research Sites

The research involved 744 academic lyceum students from three educational institutions in Uzbekistan:

1. Academic Lyceum of Jizzakh State Pedagogical University;
2. Academic Lyceum of Namangan State University;
3. No. 2 Academic Lyceum of Tashkent State Pediatric Medical University.

The experimental and control groups were formed from intact academic-lyceum classes rather than by individual random allocation. At the beginning of the experiment, the diagnostic stage was used to divide students into experimental and control groups and to equalise their initial chemistry achievement and creative-competence profiles as far as the institutional timetable allowed [11]. Accordingly, the study should be interpreted as a quasi-experimental comparison with baseline-control procedures, not as an individually randomised trial.

Baseline-equivalence note. The dissertation protocol records that students were diagnostically assessed and then equalised by group size and initial achievement before the formative intervention [11]. However, the archived article dataset contains final level counts and site-level totals, but not rater-by-rater or item-level baseline raw scores. Therefore, the revised manuscript does not overstate randomised causal inference; baseline comparability is treated as a design control and the absence of reconstructable baseline χ^2 /ANCOVA data is reported as a limitation.

At the Academic Lyceum of Jizzakh State Pedagogical University, 71 students participated in the experimental group and 69 students in the control group. At the Academic Lyceum of Namangan State University, the experimental and control groups consisted of 78 and 76 students, respectively. At No. 2 Academic Lyceum of Tashkent State Pediatric Medical University, 225 students participated in each group.

The study covered chemistry subjects including General Chemistry, Inorganic Chemistry, and Organic Chemistry. The intervention was applied in theoretical, practical, laboratory, and independent learning activities.

2.3 Assessment Criteria and Instruments

Creative competence was assessed through four main indicators:

1. Divergent thinking — the ability to propose several possible solutions to one chemical problem;
2. Scientific transfer — the ability to apply chemical knowledge in a new or non-standard situation;
3. Originality of ideas — the ability to generate uncommon, innovative, and meaningful proposals;
4. Scientific justification — the ability to support a solution using chemical concepts, laws, equations, observations, and experimental evidence.

The following instruments were used:

1. diagnostic questionnaires;
2. PISA creative-thinking tasks adapted to chemistry topics;
3. TIMSS-oriented chemistry questions;
4. graphical and tabular problems;
5. contextual and environmental chemistry tasks;
6. open-ended tasks;
7. observation sheets;
8. individual and group assignments;
9. laboratory and experimental projects;
10. creative-competence assessment rubrics;
11. self-assessment and reflection forms.

Operational scoring rubric and level thresholds.

The four article indicators were operationalized through a dissertation-based five-item analytic rubric: (1) creative solution of a chemical problem, (2) idea generation/creative thinking, (3) analytical reasoning, (4) research-experimental skills, and (5) performance on PISA/TIMSS-type international-assessment tasks [11]. Each item was scored from 1 to 5; therefore, the maximum total score was 25. The level cut-points were: 21-25 = excellent/high creative competence; 16-20 = good; 10-15 = satisfactory; and 5-9 = unsatisfactory/low.

Table 1. Operational Scoring

Rubric item	1 point	2 points	3 points	4 points	5 points
Creative solution of a chemical problem	Cannot solve the problem	Solves partially with teacher support	Uses a standard solution	Uses several solution paths	Proposes an original, scientifically justified solution
Idea generation / creative thinking	No new idea	Very few ideas	Simple ideas	New and interesting ideas	Innovative, scientifically grounded ideas
Analytical reasoning	Cannot analyse	Partial analysis	Simple analysis	Deep analysis	Scientifically analyses complex processes
Research-experimental skills	Cannot conduct an experiment	Works only with instructions	Conducts a simple experiment	Plans an experiment independently	Conducts independent inquiry and draws conclusions
International-	Cannot complete	Very low perfor-	Moderate perfor-	Completes most tasks	Completes tasks fully

assessment task perfor- mance	the task	mance	mance	correctly	and with justification
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Reliability control. Two chemistry-education specialists scored open-ended and project-based products with the same rubric; disagreements were resolved through moderation against the written descriptors. Because the submitted article file preserved only final category counts, numerical Cohen’s κ or ICC could not be reconstructed; this is now reported as a methodological limitation rather than as an unsupported reliability coefficient.

The tasks were designed to cover cognitive levels from understanding and application to analysis, evaluation, and creation. They were aligned with Bloom’s taxonomy and adapted to students’ individual levels of complexity.

Table 2. Bloom-taxonomy mapping of the task system

Bloom level	Chemistry task format	Example topic	Creative- competence indicator
Remember / Un- derstand	TIMSS-style con- ceptual question	Acids, bases, reac- tion signs	Scientific justi- fication
Apply	Contextual calcula- tion or reaction choice	Water hardness, corrosion, polymer use	Scientific trans- fer
Analyse	Graph/table inter- pretation	Reaction rate, concentration, pollution data	Analytical rea- soning
Evaluate	Case-study compari- son	Packaging materi- als, chemical safe- ty	Scientific justi- fication and originality
Create	Open-ended exper- imental/project task	Designing a water- purification or corrosion- prevention solution	Divergent think- ing and original- ity
Reflect / Improve	PISA creative- thinking improve- ment task	Revising an exper- imental plan after evidence	Idea evaluation and refinement

2.4 Instructional Intervention

The experimental groups received instruction based on an international assessment-oriented methodology. The teaching process integrated the following learning formats:

- 1. problem-based learning;
- 2. inquiry-based learning;
- 3. case-study method;

4. experimental project method;
5. STEAM approach;
6. contextual learning;
7. collaborative problem solving;
8. digital learning tools;
9. chemical modelling;
10. creative brainstorming and reflection.

The students worked with real-life chemistry problems related to water quality, environmental pollution, corrosion, chemical safety, waste recycling, acids and bases in daily life, energy sources, polymers, and industrial chemical processes. They were required to interpret graphs and diagrams, formulate alternative explanations, propose experimental procedures, create models, compare solutions, and defend their conclusions.

For example, students could be asked to analyse the causes of corrosion in a local water distribution system and develop several preventive solutions. In another task, students compared the ecological and chemical properties of different packaging materials and proposed a sustainable alternative. Open-ended experimental tasks required students to design an investigation, identify variables, predict outcomes, and explain the results scientifically.

The experimental groups were also introduced to creative problem-solving techniques such as SCAMPER, “Six Thinking Hats,” brainstorming, concept mapping, and structured reflection. In the control groups, chemistry instruction was conducted mainly through conventional explanation, textbook exercises, standard laboratory procedures, and reproductive tasks.

2.5 Data Analysis

The final achievement results were classified as excellent, good, satisfactory, and unsatisfactory on the basis of the 25-point rubric. Statistical analysis used raw frequencies, percentage distributions, Pearson’s χ^2 test, p-values, and Cramér’s V as an effect-size index. The main inferential analysis was the four-level 4×2 contingency table (achievement level $\times$ group). For a 4×2 table, $df = (4 - 1)(2 - 1) = 3$, and $\chi^2_{critical} = 7.815$ at $\alpha = .05$.

The χ^2 statistic was recomputed directly from the observed counts, not from percentages and not as an arithmetic mean of site-level statistics. Cramér’s V was calculated as $V = \sqrt{\chi^2 / [N \times \min(r - 1, c - 1)]}$. Because some site-level unsatisfactory cells had expected counts below 5, an additional sensitivity analysis merged “satisfactory” and “unsatisfactory” into one lower-achievement category and tested a 3×2 table. The pooled four-level table met the expected-count assumption.

3 Results

3.1 Results and Discussion

The final results demonstrated that the international assessment-based methodology had a positive effect on academic lyceum students' creative competence in chemistry education. The students in the experimental groups showed stronger performance in generating ideas, applying knowledge to non-standard contexts, explaining chemical processes, designing experiments, and proposing original solutions.

Table 1 presents the final distribution of students' achievement levels across the experimental and control groups.

Table 3. Final Distribution of Creative Competence Levels

Achievement level	Experimental groups, n = 374	Experimental groups, %	Control groups, n = 370	Control groups, %
Excellent	139	37.2	61	16.5
Good	162	43.3	146	39.5
Satisfactory	73	19.5	146	39.5
Unsatisfactory	0	0.0	17	4.6
Total	374	100.0	370	100.0

The proportion of students achieving excellent and good levels was 80.5% in the experimental groups and 55.9% in the control groups. The experimental groups also had no students in the unsatisfactory category, whereas 4.6% of control-group students remained at that level. These descriptive results reproduce the raw totals reported in the dissertation-based final table [11].

The results demonstrate that students exposed to contextual, creative, and international assessment-based tasks were more capable of applying chemical knowledge flexibly and independently. They showed increased confidence in analysing unfamiliar situations, proposing alternative solutions, and using scientific evidence to support their ideas.

The statistical analysis confirmed the reliability of these differences.

Table 4. Corrected Site-Level Raw Counts and Pearson's χ^2 Results

Institution	EG counts Ex/G/S/U	CG counts Ex/G/S/U	$\chi^2(4 \times 2)$	df	P	Cramer's V	Conclusion
Jizzakh State Pedagogical University Academic Lyceum	29/33/9/0	9/28/27/5	24.91 3	3	< .001	.422	Significant
Namangan State	33/35/10/0	12/29/28/7	25.86 7	3	< .00	.410	Significant

University Academic Lyceum No. 2	77/94/54/0	40/89/91/5	26.27	3	<	.242	Signifi- cant
Academic Lyceum of Tash- kent Pedi- atric Med- ical Insti- tute			9		.00		
Pooled result, N = 744	139/162/73 /0	61/146/146/ 17	72.56 5	3	<	.312	Signifi- cant
					.00		
					1		

The corrected χ^2 values are substantially larger than the previously reported values because they were recomputed from the actual 4×2 frequency tables. The pooled result was $\chi^2(3, N = 744) = 72.565, p < .001$, Cramér's $V = .312$, indicating a statistically significant and educationally meaningful association between group membership and final creative-competence level. The site-level tests were also significant: Jizzakh $\chi^2(3, N = 140) = 24.913, p < .001, V = .422$; Namangan $\chi^2(3, N = 154) = 25.867, p < .001, V = .410$; and Tashkent $\chi^2(3, N = 450) = 26.279, p < .001, V = .242$.

Table 5. Expected-Count Check and Merged-Category Sensitivity Analysis

Institution	Minimum expected count in 4×2 table	Reason for sensitivity check	$\chi^2(3\text{-level})$	df	p
Jizzakh	2.464	Unsatisfactory expected count < 5	23.815	2	< .001
Namangan	3.455	Unsatisfactory expected count < 5	24.230	2	< .001
Tashkent	2.500	Unsatisfactory expected count < 5	23.597	2	< .001
Pooled	8.454	Assumption acceptable	65.554	2	< .001

Pedagogical effectiveness was recalculated transparently as the percentage-point difference in the share of students at excellent + good levels: Effectiveness = (EGexcellent+good/NEG × 100) - (CGexcellent+good/NCG × 100). By this formula, the site-level gaps were 33.70 percentage points in Jizzakh (87.32% vs. 53.62%), 33.23 percentage points in Namangan (87.18% vs. 53.95%), and 18.67 percentage points in Tashkent (76.00% vs. 57.33%). The pooled gap was 24.56 percentage points (80.48%

vs. 55.95%). Thus, the revised manuscript no longer reports an arithmetic mean of χ^2 values or undefined indicators.

3.2 Discussion

The findings support the hypothesis that the integrated international assessment-oriented methodology was associated with higher final creative-competence levels in chemistry education. Because the intervention was implemented as a bundled pedagogical package, the results should be interpreted as evidence for the combined methodology rather than as proof that any single component alone produced the effect.

The results may be explained by the structure of the intervention. Traditional chemistry instruction often prioritises correct answers, algorithms, equations, and standard laboratory procedures. These elements remain essential, but they are insufficient for developing creative competence. Students also need opportunities to formulate questions, generate alternative hypotheses, interpret evidence, design investigations, construct models, and improve their ideas through feedback.

Within this integrated package, PISA-oriented tasks provided open-ended situations in which students generated, evaluated, and improved ideas [1], [7]. These features are theoretically consistent with chemistry creativity; however, the present design did not isolate PISA tasks from the other active-learning components.

TIMSS-oriented knowing, applying, and reasoning tasks provided a complementary cognitive sequence [2]. In the intervention, these tasks were combined with contextual cases, laboratory projects, STEAM activities, digital tools, SCAMPER, and collaborative reflection. Therefore, the discussion frames these elements as mutually reinforcing parts of one methodology rather than as separately tested causal factors.

The findings are consistent with previous research on project-based and STEAM-oriented chemistry learning. Ananda, Rahmawati, and Khairi [5] showed that integrating design thinking with STEAM project-based learning can support students' critical thinking and problem-solving in chemistry. Their study used contextual environmental problems related to redox chemistry, illustrating the importance of connecting chemical concepts with real-life issues.

Similarly, Domenici [6] demonstrated that STEAM project-based activities can promote multidisciplinary and creative learning in chemistry education. The present study extends these findings by showing that PISA and TIMSS-oriented tasks can provide a structured framework for such activities in academic lyceums.

Contextual chemistry tasks appeared pedagogically valuable because they connected plastic waste, corrosion, water purification, acids and bases, polymers, energy resources, and chemical safety with real-life decision making. This interpretation is consistent with observed classroom processes, but it should be treated as an explanatory hypothesis for future component-analysis studies.

Project-based and inquiry-based activities gave students opportunities to consider alternatives, collect evidence, discuss ideas, and revise conclusions. Since these activities were delivered together with assessment-based tasks, the study cannot determine whether the observed improvement was due to international-assessment task design, general active learning, creativity techniques, or their interaction.

Digital resources, graphs, diagrams, simulations, and online information sources supported multi-format work with chemical information. Again, the claim is pedagogical rather than decompositional: the present quasi-experiment tested the entire instructional configuration.

The methodological model also promoted differentiated learning. Graphical and contextual tasks were presented with varying levels of complexity, allowing students to progress from guided application to independent analysis and creation. This adaptive approach supported students with different levels of prior knowledge while maintaining a common focus on creative competence.

The study has theoretical significance because it demonstrates that creative competence in chemistry should be understood as an integrated construct. It includes divergent thinking, originality, scientific transfer, reasoning, experimental planning, reflection, and evidence-based justification. It should not be reduced to artistic expression or free imagination; rather, it should be developed through scientifically meaningful tasks.

The study also has practical significance. The developed methodology may be used by chemistry teachers in academic lyceums, specialised schools, and pre-university science programmes. The tasks may be adapted for General Chemistry, Inorganic Chemistry, Organic Chemistry, Analytical Chemistry, and Environmental Chemistry.

Several limitations should be considered. First, the study used intact classes in three academic lyceums; therefore, the evidence is quasi-experimental and should not be interpreted as an individually randomised causal trial. Second, the Tashkent site ($n = 450$) was much larger than the Jizzakh and Namangan sites combined and therefore dominated the pooled estimate; for this reason, the revised results report both site-level and pooled tests. Third, the intervention bundled PISA/TIMSS tasks with STEAM, digital tools, SCAMPER, Six Thinking Hats, projects, and collaborative learning; the study cannot decompose the separate effects of these components. Fourth, although a rubric and moderation procedure were used, the archived article dataset did not contain rater-by-rater scores, so Cohen's κ or ICC could not be computed retrospectively. Fifth, the diagnostic stage was used to equalise groups, but reconstructable baseline raw counts were not available for ANCOVA or gain-score modelling.

Future studies should investigate the long-term impact of the methodology, analyse the separate effects of digital tools and laboratory projects, and explore how international assessment-based creativity tasks may be adapted for chemistry olympiad preparation and teacher professional development.

4 Conclusion

The study confirmed that international assessment-based tasks are effective tools for developing academic lyceum students' creative competence in chemistry education.

First, PISA creative-thinking tasks and TIMSS-oriented chemistry tasks created conditions for students to use chemical knowledge in non-standard and real-life situa-

tions. Through such tasks, students learned to analyse problems, generate alternatives, justify solutions, and improve ideas.

Second, the methodology improved students' ability to apply chemical concepts creatively through contextual tasks, graphical problems, case studies, experimental projects, STEAM activities, and inquiry-based learning.

Third, the final results demonstrated a statistically significant advantage of the experimental groups. The corrected pooled analysis was $\chi^2(3, N = 744) = 72.565$, $p < .001$, Cramér's $V = .312$; the excellent/good gap was 24.56 percentage points in favour of the experimental groups.

Fourth, the integrated methodology was associated with higher levels of divergent thinking, scientific transfer, originality, and scientific justification. Because the intervention was bundled, future research should test the separate contribution of PISA tasks, TIMSS tasks, STEAM projects, digital tools, and creativity techniques through dismantling or factorial designs.

Based on the findings, the following suggestions are recommended:

1. Chemistry teachers should regularly use PISA and TIMSS-oriented contextual tasks in classroom, laboratory, and independent learning activities.
2. Chemistry curricula should include more open-ended, graph-based, analytical, and project-oriented tasks that require students to generate and justify original ideas.
3. Assessment should evaluate not only factual knowledge but also students' ability to interpret evidence, design experiments, propose alternative solutions, and improve ideas through reflection.
4. Teacher professional-development programmes should include training on international assessment frameworks, task design, creativity assessment, and the use of digital resources in chemistry teaching.
5. Further research should archive item-level baseline data and rater-level scoring data so that gain scores, ANCOVA, Cohen's κ , ICC, and more robust multilevel analyses can be reported.

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