Design Thinking-Based Chemistry Instruction for Concept Application and Problem-Solving Skills Among Secondary School Students: A Quasi-Experimental Study Protocol

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ABSTRACT

Background. Secondary chemistry requires students to transfer concepts to unfamiliar situations, interpret evidence and construct explanations. A structured design-thinking process may provide repeated opportunities to practise these behaviours.

Aim. To evaluate, in a prospective school-based study, whether a six-week design thinking-based chemistry programme improves concept application and problem-solving skills compared with conventional chemistry instruction.

Methods. This protocol describes a quasi-experimental pre-test/post-test comparison-group study among secondary school students. The intervention consists of six weekly cycles involving understanding a context, defining a chemistry problem, generating alternatives, developing a solution, testing evidence and revising the solution. The primary outcomes will be scores on a Concept Application Test (CAT) and a Problem-Solving Skills Test (PSST). The instruments will undergo expert review, pilot testing, reliability assessment and rubric-based scorer training before the main study. The sample size will be determined a priori using a formal power calculation. Baseline-adjusted post-test comparisons will account for clustering by class or teacher where applicable.

Expected contribution. The study is designed to provide empirical evidence on a clearly specified, chemistry-specific design-thinking intervention. No synthetic or simulated observations are presented as study findings in this protocol.

Keywords: design thinking; chemistry education; secondary school; concept application; problem-solving; active learning; study protocol.

INTRODUCTION

Chemistry learning involves movement between observations, representations, explanations and calculations. Students may recall a chemical rule yet have difficulty identifying when that rule is relevant in an unfamiliar situation. Instruction that asks learners to interpret a context, select a principle, justify a solution and reconsider the result may therefore target a different layer of learning from routine recall.

Design thinking provides a structured approach to open-ended problem work. Educational versions commonly involve understanding a context, defining a problem, generating alternatives, developing a solution, testing it and revising it. A 2024 meta-analysis of 25 empirical articles reported an overall positive relationship between design thinking and student learning, while identifying variation by outcome, duration, grade level and model [1]. A 2026 meta-analysis of 44 effect sizes likewise reported positive effects on

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STEM learning and identified learner type, instructional model, learning environment and intervention duration as moderators [2].

Chemistry is a useful setting because classroom problems can be connected to observable phenomena, experimental evidence, material properties, reactions and quantitative reasoning. A high-school chemistry study specifically examined design-thinking instruction and reported improvements in several problem-finding and problem-solving outcomes [3]. Broader reviews of high-school chemistry pedagogy also support evaluation of active and alternative instructional approaches, although effects vary across methods [4].

The present study therefore focuses on two immediate competencies: applying chemistry concepts to new contexts and solving non-routine chemistry problems. The intervention has been designed specifically for this study and is not presented as a replication of any cited investigation.

Need for the Study

A student can answer a familiar textbook question without necessarily being able to decide how to approach a new problem. Concept application requires selection and transfer of relevant knowledge, whereas problem-solving requires planning, execution, evaluation and revision. Design thinking offers a practical classroom sequence for making these processes visible. Because published evidence indicates that effects vary with instructional model and duration [1,2], a clearly specified subject-specific intervention should be evaluated prospectively rather than inferred from simulated data.

Statement of the Problem

A study to evaluate the effect of design thinking-based chemistry instruction on concept application and problem-solving skills among secondary school students.

Aim

To evaluate the effect of design thinking-based chemistry instruction on concept application and problem-solving skills among secondary school students.

Objectives

- To assess baseline concept application and problem-solving performance in the participating groups.
- To implement a six-week, chemistry-specific design thinking-based instructional programme.
- To determine post-test concept application after the intervention.
- To determine post-test problem-solving performance after the intervention.
- To compare baseline-adjusted post-test outcomes between the design-thinking and conventional-instruction groups.
- To examine the exploratory relationship between changes in concept application and problem-solving.

Research Questions

- What are the baseline concept-application and problem-solving scores of participating students?
- Does the design thinking-based programme improve concept application?
- Does the programme improve problem-solving performance?
- Is the magnitude of improvement different from that observed under conventional instruction?
- Are changes in concept application and problem-solving associated?

Hypotheses

- $H0_1$: There is no significant difference in post-test concept-application scores between the design-thinking and conventional-instruction groups after adjustment for baseline scores.

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- $H0_2$: There is no significant difference in post-test problem-solving scores between the design-thinking and conventional-instruction groups after adjustment for baseline scores.
- $H0_3$: There is no significant association between changes in concept application and problem-solving.

MATERIALS AND METHODS

Study Design

A prospective quasi-experimental pre-test/post-test comparison-group study will be conducted in a secondary-school setting. Students will be assessed before and after six weeks of instruction. The study will use real participant data collected prospectively; no synthetic observations will be used for the study's results or statistical inference.

Study Setting and Participants

The proposed setting is a secondary school offering chemistry as part of the science curriculum. Eligible students will be recruited according to predefined inclusion and exclusion criteria agreed with the participating school and research team.

The final sample size will be determined by an a priori power calculation based on the primary outcome, expected effect size, significance level, desired statistical power and anticipated attrition. Where students are taught in intact classes, the calculation and analysis will account for the clustering effect.

Allocation and Comparison Group

Where feasible, eligible classes will be allocated to the design-thinking or conventional-instruction condition using a predefined allocation procedure. If random allocation is not feasible because of school scheduling or administrative constraints, the allocation process and baseline comparability of groups will be documented transparently.

The comparison group will receive conventional chemistry teaching during the same six-week period. Lesson content, teaching time, teacher characteristics and additional learning exposure will be recorded to permit interpretation of between-group differences.

Design Thinking Intervention

The six-week intervention was independently designed for this study. Each weekly cycle connects a chemistry concept with a contextual problem and requires students to understand the situation, define the task, generate alternatives, develop a solution, test evidence and revise their reasoning.

Week	Focus	Student activity	Planned output
1	Understand	Analyse a chemistry situation, observations and constraints.	Context map
2	Define	Convert the situation into a specific chemistry problem.	Problem statement
3	Ideate	Generate and compare possible explanations or solution routes.	Idea matrix
4	Develop	Construct a model, calculation pathway,	First solution

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		procedure or prototype.	
5	Test	Compare predictions with observations or data.	Test record
6	Revise	Identify weaknesses and improve the solution.	Revised solution and reflection

Teacher Role and Intervention Fidelity

- Provide the required chemistry concepts and safety guidance.
- Ask students to justify decisions with chemical evidence.
- Use questioning to identify misconceptions.
- Allow more than one solution when it meets the predefined chemistry criteria.
- Require students to document what changed after testing.
- Use an intervention checklist to document delivery of each weekly component.
- Record deviations, missed sessions and material differences between groups.

Outcome Measures

The primary outcomes will be performance on two study-specific instruments: the 40-point Concept Application Test (CAT) and the 30-point Problem-Solving Skills Test (PSST). These instruments are proposed measures and will not be treated as validated until the planned expert review, pilot testing and reliability assessment have been completed.

CAT component	**Maximum score**
Concept recognition	8
Contextual application	12
Evidence-based explanation	10
Justification	10
Total	40

PSST component	**Maximum score**
Problem definition	5
Planning	5
Relevant information	5
Execution	7
Evaluation/revision	8
Total	30

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Instrument Development and Quality Assurance

Before the main study, the CAT and PSST will undergo expert review for content relevance, clarity and alignment with the study objectives. A pilot administration will be conducted in a comparable student population not included in the main analysis. Item performance, internal consistency and, where applicable, inter-rater agreement for open-ended responses will be examined. Scorers will receive standardised instructions and use explicit rubrics. Necessary revisions will be completed before baseline data collection.

Data Collection Procedure

- Obtain institutional and school permissions before recruitment.
- Obtain appropriate parent/guardian consent and student assent where required.
- Administer CAT and PSST under standardised pre-test conditions.
- Deliver the assigned six-week instructional programme.
- Monitor intervention fidelity and record attendance and protocol deviations.
- Administer the same outcome domains under standardised post-test conditions.
- Enter, verify and de-identify data before analysis.

Ethics

The main study will begin only after approval from the relevant institutional ethics/research authority and school administration, as applicable. Participation will follow appropriate consent/assent procedures. Student identities and research scores will be kept confidential, and research scores will not be used for punitive academic decisions.

Statistical Analysis Plan

The primary analysis will compare post-test CAT and PSST scores between groups after adjustment for baseline scores. If students are nested within classes or teachers, linear mixed-effects models with an appropriate class/teacher random effect will be considered. Adjusted mean differences will be reported with 95% confidence intervals and standardised effect sizes with confidence intervals where appropriate.

Descriptive statistics will summarise participant characteristics, attendance and outcome distributions. Baseline group characteristics will be described rather than used as a reason to selectively exclude participants. Within-group pre/post changes may be reported as secondary descriptive analyses.

The exploratory association between changes in CAT and PSST will be assessed using Pearson or Spearman correlation according to distributional assumptions. The statistical analysis plan will be finalised before unblinding/group comparison of the primary outcomes. A two-sided $p<0.05$ will be used for prespecified inferential tests, with interpretation based primarily on effect estimates and confidence intervals.

Missing data will be described. The primary analysis will follow a prespecified missing-data strategy, with sensitivity analyses where appropriate. No statistical significance testing will be performed on simulated or synthetic observations.

Expected Outcomes

The study is designed to determine whether students receiving the design thinking-based chemistry programme demonstrate greater improvement in concept application and problem-solving than students receiving conventional instruction. Because data have not yet been prospectively collected, numerical results, p-values, confidence intervals and effect sizes are intentionally not presented in this protocol.

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DISCUSSION AND RATIONALE

The intervention is built around repeated problem definition, idea generation, development, testing and revision. This is consistent with the design-thinking literature, which suggests positive learning associations while also showing variation by outcome, grade, duration and instructional model [1,2]. The chemistry-specific rationale is supported by previous high-school chemistry research examining design thinking [3]. The present programme differs in its duration, classroom outputs and outcome construction, so the cited study is used as conceptual background rather than as a source of the present study's data.

The broader chemistry pedagogy literature supports testing active and problem-oriented approaches, although the magnitude of benefit varies across interventions [4,5]. The proposed study addresses this gap by specifying the intervention, outcomes, quality-assurance procedures and analysis before real student data are collected.Open-ended design tasks also create practical challenges. They require careful time management, strong content guidance, adequate resources and consistent assessment. Without explicit chemistry criteria, a project may become focused on producing an attractive object rather than demonstrating chemical reasoning. Intervention fidelity and teacher preparation will therefore be important components of the study.

Strengths

- Chemistry-specific rather than a generic design-thinking intervention.
- Clearly staged six-week instructional sequence.
- Separate measures for concept application and problem-solving.
- Prospective data collection rather than presentation of simulated observations as findings.
- Planned expert review, pilot testing, reliability assessment and scorer training.
- Analysis plan designed to account for baseline differences and classroom/teacher clustering where applicable.

Anticipated Limitations

- The quasi-experimental design may retain residual confounding if random allocation is not feasible.
- The CAT and PSST require empirical validation before they can be considered established measurement instruments.
- Classroom clustering and intervention fidelity may introduce variability.
- A six-week intervention may not establish long-term retention or transfer.
- School-specific context may limit generalisability.

Implications for Chemistry Education

- Use authentic chemistry problems with explicit success criteria.
- Require students to justify decisions with chemical evidence.
- Include testing and revision rather than grading only the first solution.
- Use written reflections to expose changes in student reasoning.
- Validate instruments before using them for formal research claims.
- Document intervention fidelity so that successful components can be replicated.

CONCLUSION

This protocol presents a subject-specific six-week design thinking-based approach for secondary chemistry education. It is designed to prospectively evaluate concept application and problem-solving using defined outcomes, quality-assured instruments and a prespecified statistical approach. No claim of effectiveness is made before real student data are collected. The protocol is intended to support a transparent and reproducible empirical evaluation.

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Declarations

Item	Statement
Ethics approval	To be obtained from the relevant institutional and/or school authority before participant recruitment, as applicable.
Consent/assent	Appropriate consent and assent procedures will be followed before data collection.
Funding	To be declared by the research team.
Conflict of interest	To be declared by the research team.
Data availability	Participant-level data will be made available according to institutional policy, consent requirements and journal policy.
Author contributions	To be finalised by the actual research team.

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APPENDIX A. PROPOSED STUDY FLOW

Stage	Activity
1	Ethics/institutional approval and school permissions
2	Recruitment, eligibility screening and consent/assent
3	Expert review and pilot validation of CAT and PSST
4	Baseline CAT and PSST
5	Six-week intervention/comparison teaching
6	Intervention fidelity and attendance monitoring
7	Post-test CAT and PSST
8	Data cleaning, blinded analysis and reporting