

A Pilot Study on the Feasibility and Preliminary Impact of TriChem in Enhancing Interest and Conceptual Understanding of Mole Concept, Chemical Formula, and Equations

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ABSTRACT

The Mole Concept, Chemical Formula, and Chemical Equation are consistently identified as challenging topics in secondary school chemistry due to their abstract representations and mathematical complexity, often resulting in low student engagement and conceptual difficulties. This pilot study examined the feasibility and preliminary effectiveness of TriChem, a hybrid game-based learning tool integrated within the 5E instructional model, in enhancing students' interest and conceptual understanding of mole-related concepts. A one-group pretest–posttest design was implemented with 19 Form 4 students in a Malaysian secondary school. Data were analysed using descriptive statistics and reliability analysis (Cronbach's $\alpha = 0.880$). Post-intervention results showed increases in mean interest scores (4.04 to 4.31) and engagement scores (4.25 to 4.66). Qualitative feedback indicated reduced calculation-related anxiety and improved conceptual reasoning. Although limited by its small sample size, the findings suggest that TriChem demonstrates promising feasibility and pedagogical value, warranting further large-scale investigation.

Keywords: game-based learning; mole concept; stoichiometry; 5E instructional model; pilot study

INTRODUCTION

Chemistry is widely recognised as a central science due to its foundational role in explaining phenomena across disciplines such as biology, physics, and environmental science (Thote & S, 2021). Within secondary education, chemistry plays a crucial role in developing scientific literacy and higher-order thinking skills aligned with 21st-century educational goals (Sewagegn & Diale, 2019). In Malaysia, the KSSM Chemistry Curriculum emphasises inquiry-based learning, higher-order thinking skills (HOTS), and real-world application of scientific knowledge to foster active and meaningful learning experiences.

Despite these curricular intentions, several studies have reported persistent challenges in students' engagement and conceptual understanding in chemistry, particularly in abstract and calculation-intensive topics (Draman & Mohd, 2021). One such topic is the Mole Concept, Chemical Formula, and Chemical Equation, which requires students to bridge macroscopic observations, symbolic representations, and mathematical reasoning. Research consistently identifies stoichiometry and mole-related concepts as areas prone to misconceptions, procedural memorisation, and calculation anxiety. These challenges often lead to reduced motivation and passive classroom participation.

Although game-based learning and inquiry-based models such as the 5E instructional framework have demonstrated positive effects on engagement and conceptual understanding, limited studies have examined the integration of hybrid physical–digital game tools within a structured 5E approach specifically targeting mole concept learning in Malaysian secondary classrooms. Furthermore, preliminary feasibility evidence is still limited at the school implementation level.

Therefore, this pilot study aimed to examine the feasibility and preliminary effectiveness of TriChem, a hybrid game-based learning tool embedded within the 5E instructional model, in enhancing students' interest and conceptual understanding of mole-related concepts.

Objective

1. To examine the feasibility and classroom implementation of TriChem as a hybrid game-based tool aligned with the 5E instructional model.
2. To determine changes in students' interest and engagement towards mole-related concepts following the TriChem intervention.
3. To explore students' perceptions regarding the usefulness of TriChem in supporting conceptual understanding and reducing calculation-related anxiety.

METHODOLOGY

This study employed a one-group pretest–posttest pilot design to examine the feasibility and preliminary effectiveness of TriChem as a hybrid game-based instructional intervention. The pilot design was selected to evaluate classroom implementation practicality and generate preliminary empirical evidence prior to large-scale testing.

The participants consisted of 19 Form 4 students from a Malaysian secondary school (SMK Damai Jaya). The class was selected using convenience sampling due to accessibility during the practicum period. All participants had previously been introduced to basic mole concepts as part of the national curriculum.

The development of TriChem followed the ADDIE instructional design model: Analysis, Design, Development, Implementation, and Evaluation (Almelhi, 2021).

Analysis Phase

Classroom observations and informal discussions with students revealed low engagement and difficulty in mole-related topics, particularly in balancing equations and performing mole calculations. These challenges were associated with abstract symbolic representation and procedural memorisation.

Design Phase

The 5E instructional model (Engage, Explore, Explain, Elaborate, Evaluate) was integrated into the game structure to ensure alignment with inquiry-based pedagogy.

Development Phase

Three card-based games were developed:

- Chemistry Family
- Tic-Tac-Mol
- ChemEmpire

Each game incorporated QR codes linking to digital explanations and answer verification materials. The module and instruments were validated by three subject matter experts. The questionnaire demonstrated high internal consistency reliability (Cronbach's $\alpha = 0.880$).

The intervention was conducted during regular chemistry lessons. The TriChem implementation followed the 5E phases:

- Engage: Introduction of game objectives to activate prior knowledge.
- Explore: Students interacted with game cards to solve mole-related problems collaboratively.
- Explain: Students discussed strategies and reasoning with teacher facilitation.
- Elaborate: QR code resources were accessed for feedback and deeper explanation.
- Evaluate: Performance scores and reflective feedback were collected.

The intervention emphasised collaborative learning, immediate feedback, and structured inquiry.

Two instruments were used:

1. A Likert-scale questionnaire measuring:
 - Interest
 - Engagement
 - Satisfaction
2. Open-ended questions to explore:
 - Perceived usefulness
 - Conceptual understanding
 - Anxiety reduction

The questionnaire consisted of 14 items with high internal consistency ($\alpha = 0.880$).

Pre-test questionnaires were administered before the intervention to measure baseline interest and engagement. Post-test questionnaires and open-ended responses were collected immediately after the intervention.

Quantitative data were analysed using descriptive statistics (mean scores) to identify changes in interest and engagement levels. Qualitative responses were analysed using thematic analysis to identify recurring themes related to conceptual understanding and calculation anxiety.

RESULT

Instrument Reliability

Prior to the pilot implementation, the internal consistency reliability of the questionnaire was examined. The 14-item instrument demonstrated high reliability, with a Cronbach's alpha coefficient of 0.880, indicating strong internal consistency and suitability for measuring students' interest and engagement constructs.

Feasibility and Classroom Implementation

The TriChem intervention was successfully implemented within a regular classroom setting without procedural disruption. Students were able to follow the game instructions, utilise QR code resources, and complete collaborative tasks within the allocated lesson period. Observational feedback indicated active participation, peer discussion, and appropriate use of digital support materials. These findings suggest that TriChem demonstrates practical feasibility for classroom integration.

Changes in Students' Interest and Engagement

Descriptive analysis revealed positive changes across measured constructs following the intervention.

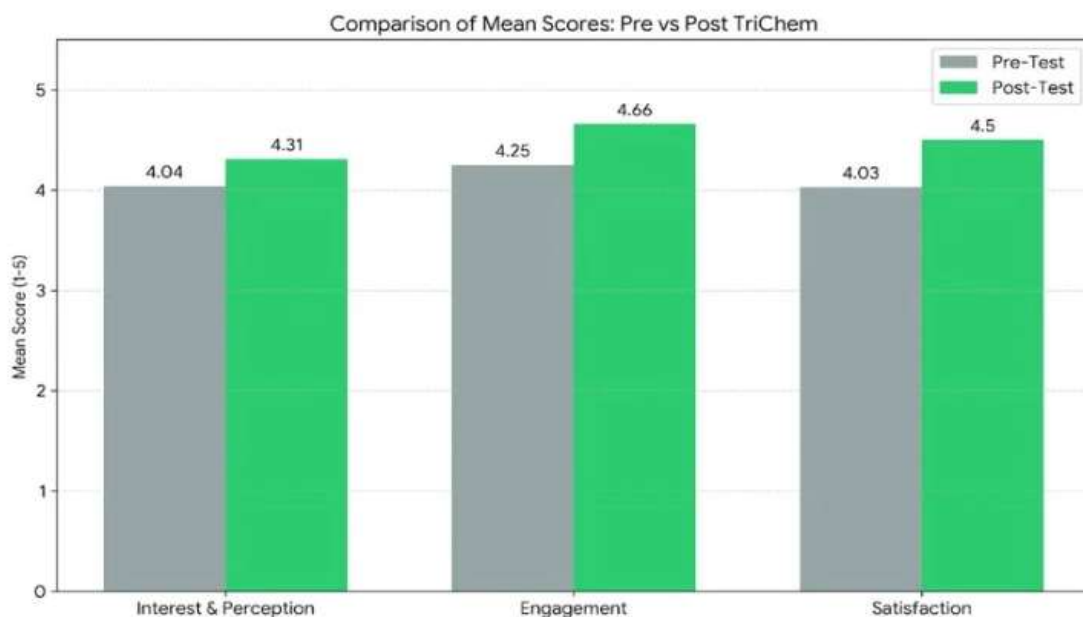


Figure 1

Overall Interest and Perception

The overall mean score increased from 4.04 (pre-test) to 4.31 (post-test), indicating an upward trend in students' interest toward mole-related concepts.

Engagement

Mean engagement scores increased from 4.25 to 4.66, reflecting enhanced classroom involvement and collaborative interaction during the intervention.

Satisfaction

Students' satisfaction scores rose from 4.03 to 4.66, suggesting favourable acceptance of the TriChem learning approach.

All post-intervention mean values exceeded 3.81, which falls within the "high" category based on the instrument scale. These results indicate preliminary evidence of improved student engagement following the TriChem implementation.

Perceptions of Individual TriChem Games

Thematic analysis of open-ended responses identified three major themes:

1. Conceptual Shift from Memorisation to Understanding

Students reported improved ability to visualise chemical equations and understand reactant-product relationships.

2. Reduced Calculation Anxiety

Participants indicated that game mechanics reduced perceived mathematical pressure, allowing them to engage in mole calculations without test-related stress.

3. Positive Reception of Hybrid Features

The integration of QR code feedback and digital explanations was perceived as supportive and aligned with modern learning preferences.

These qualitative findings provide complementary evidence supporting the preliminary impact and feasibility of the TriChem intervention.

DISCUSSION

Preliminary Impact on Students' Interest and Engagement

Kit helps in the transformation from passive traditional methods to more engaging methods. Teachers can use this “TriChem” as a teaching tool in order to increase students' interest and motivation in Chemistry, especially for the abstract concept, challenging topic - Mole concept, chemical formula and equations. It is because this topic is the most fundamental topic that will be applied into more complex topics further. The findings of this pilot study indicate a positive shift in students' interest and engagement following the TriChem intervention. The increase in mean scores for interest, engagement, and satisfaction suggests that integrating structured game-based activities within the 5E instructional framework may support more active classroom participation. Although the improvements were measured descriptively, the upward trend across all constructs provides preliminary evidence of pedagogical value.

The enhancement in engagement may be explained through constructivist principles, where learners actively construct knowledge through interaction and collaboration. The use of card-based gameplay combined with inquiry phases (Engage–Explore–Explain–Elaborate–Evaluate) likely promoted active cognitive involvement rather than passive information reception.

Conceptual Understanding and Confidence in Mole-Related Topics

Item-level analysis revealed sustained or improved confidence in balancing equations, understanding mole relationships, and performing calculations. These findings suggest that TriChem may have supported conceptual reinforcement, particularly in topics traditionally associated with procedural memorisation.

Moreover, the usage of TriChem kit has aligned with 21st-century technology, as there is integration of QR codes in every card game, helping students in giving immediate feedback and videos for students to understand more well. The tactile manipulation of reactant–product cards and immediate QR-code feedback may have reduced extraneous cognitive load by providing structured guidance and instant clarification. From a cognitive load perspective, embedding calculation tasks within a familiar game structure may help redistribute cognitive effort from anxiety-driven processing toward meaningful reasoning.

However, as this was a pilot study without inferential statistical testing, these interpretations should be considered preliminary rather than conclusive.

Reduction of Calculation-Related Anxiety

Qualitative responses consistently indicated reduced anxiety toward mole calculations. Students reported that competitive gameplay shifted their focus from “difficulty of mathematics” to “strategy of play.” This aligns with affective learning theories suggesting that positive emotional engagement can lower performance-related anxiety and increase task persistence.

By embedding dimensional analysis and unit factor reasoning within structured gameplay, TriChem may have indirectly supported mathematical confidence. While anxiety was not quantitatively measured as a separate construct, student narratives provide initial insight into the intervention's affective impact.

Feasibility of Hybrid Game-Based 5E Integration

The successful classroom implementation without procedural disruption indicates that TriChem demonstrates practical feasibility in a secondary school setting. Students were able to navigate game rules, collaborate effectively, and utilise digital QR-based support independently.

The hybrid physical–digital design appears to bridge traditional hands-on interaction with immediate technological feedback. This integration may address the common issue of delayed corrective feedback in conventional chemistry instruction, thereby supporting timely conceptual clarification.

Implications for Chemistry Pedagogy

The findings suggest that structured game-based inquiry tools such as TriChem may serve as complementary instructional strategies for abstract, calculation-intensive topics. Rather than replacing conventional instruction, such tools may enhance engagement and provide alternative representations for mole-related reasoning.

Nevertheless, given the small sample size and absence of a control group, the results should be interpreted cautiously. Larger-scale quasi-experimental studies are necessary to determine statistical significance and long-term retention effects.

Limitations and Future Research Directions

Although the findings of the pilot test are promising, several limitations should be acknowledged. As is typical for a pilot study, the sample size ($N = 19$) is relatively small, which limits the generalisability of the findings to a broader population. Future studies should involve a larger and more diverse sample across different school types and geographical locations to enable more robust statistical analyses.

In addition, the current study did not include a long-term retention test. Therefore, it remains unclear whether the conceptual improvements observed are sustained over time. Future research should incorporate follow-up retention assessments several months after the intervention to determine the durability of students' conceptual understanding.

Another limitation concerns the depth of conceptual learning facilitated by the technological features. While scanning cards or viewing 3D particle models may enhance visualisation, students may not necessarily develop a deeper understanding of the relationships between mass, volume, and number of particles. Future research should therefore explore instructional scaffolding strategies or guided inquiry approaches to strengthen students' conceptual integration.

Finally, future iterations of TriChem could incorporate Augmented Reality (AR) features to further enhance sub-microscopic visualisation and provide a more immersive and interactive learning experience, while ensuring that technological enhancements are pedagogically aligned with learning objectives.

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CONCLUSION

In short, “TriChem” plays an essential role in providing students with the opportunity to learn chemistry in a more enjoyable way. In other words, this kit is able to create an active learning environment through Chemistry Family, Tic-Tac-Mol and Chem Empire, where the students are encouraged to have social interaction and peer cooperation. This kit helps in the transformation from passive traditional methods to more engaging methods. Teachers can use this “TriChem” as a teaching tool in order to increase students’ interest and motivation in Chemistry, especially for the abstract concept, challenging topic - Mole concept, chemical formula and equations. It is because this topic is the most fundamental topic that will be applied into more complex topics further. Moreover, the usage of TriChem kit has aligned with 21st-century technology, as there is integration of QR codes in every card game, helping students in giving immediate feedback and videos for students to understand more well. From the perspective of the community, by implementing this “TriChem” as a learning aid to foster a positive attitude towards chemistry in the topic of mole concept, formula and chemical equations. Automatically, students will start engaging actively in class. Hence, this game-based learning is able to encourage healthy competition and increase their interest in chemistry.

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