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Validation of a Game-Based Chemistry Learning Module (KimCraft): Expert Review and Preliminary Findings

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ABSTRACT: Chemistry is a core subject that plays an important role in developing students' scientific literacy. However, abstract topics such as Matter and Atomic Structure often pose significant challenges, leading to misconceptions, low academic achievement, and negative attitudes toward learning chemistry. In line with Sustainable Development Goal 4 (SDG 4), a game-based learning module known as KimCraft was developed using Minecraft Education to support the teaching of this topic in a more interactive manner. The module was designed based on the ADDIE instructional design model and grounded in Vygotsky's Social Constructivism Theory, which emphasizes collaborative learning and instructional scaffolding within the Zone of Proximal Development. This study aimed to evaluate the content validity of the module through expert review. A 23-item checklist was assessed by nine experts and analysed using the Content Validity Index (CVI). The findings showed that both the I-CVI and S-CVI/Ave achieved a value of 1.00, indicating excellent content validity. These results confirm that the KimCraft module is relevant, curriculum-aligned, and has strong potential to support more effective and engaging chemistry learning.

INTRODUCTION

Chemistry education plays a vital role in shaping students' scientific literacy. As a branch of science, chemistry focuses on understanding the properties, structure, and transformations of matter at the microscopic level. A strong grasp of these concepts is essential, as they help explain natural phenomena and underpin the development of modern technologies (Vivas-Reyes et al., 2024). One of the core topics in Malaysia's secondary school Chemistry Curriculum is Matter and Atomic Structure, as outlined in the Form Four Chemistry Curriculum and Assessment Standard Document (DSKP) by the Ministry of Education Malaysia (2018).

However, many students face significant challenges in grasping abstract concepts such as matter and atomic structure. These ideas exist at the submicroscopic and symbolic levels, which often lead to misconceptions and poor academic performance (Azizoglu et al., 2022; Nkadimeng & Ankiewicz, 2022). Negative attitudes toward Chemistry are also common, with students perceiving it as too abstract, difficult, and disconnected from real life (Legerén Lago, 2017). At the same time, students often lack self-directed learning skills, rely heavily on teachers and remain passive in traditional classroom settings

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(Chen et al., 2022).

In line with Sustainable Development Goal (SDG 4), which emphasizes inclusive, equitable, and quality education by 2030, there is a growing need to strengthen pedagogical practices through innovative, technology-integrated approaches (Zickafoose et al., 2024). To meet this need, the Game-Based Chemistry Learning module was developed using the Minecraft Education platform. The module aims to support students' achievement in Chemistry, foster positive attitudes toward the chemistry subject, and promote self-directed learning.

RESEARCH BACKGROUND

Chemistry is one of the core subjects within the Science, Technology, Engineering, and Mathematics (STEM) disciplines and plays a vital role in nurturing students' scientific literacy. Mastery of chemistry not only helps students understand natural phenomena through a scientific lens but also serves as a foundational qualification for careers in health sciences, engineering, and technology-related fields. As the demands of the 21st-century workforce increasingly prioritize scientific and analytical competencies, effective chemistry education is essential for producing knowledgeable and highly skilled human capital (Agiande et al., 2024; Vivas-Reyes et al., 2024).

Despite its importance, many students around the world face significant challenges in mastering chemistry. International studies have reported persistent difficulties among secondary school students in countries such as Kenya (Gatumwa et al., 2022; Jane et al., 2017), Nigeria (Agiande et al., 2024; Iyiola & Ezeh, 2024), the Philippines (Cruz et al., 2024), Rwanda (Nsabayezu et al., 2023), and Taiwan (Sufen Chen et al., 2020). Similar challenges are evident in Malaysia, where national examination results (SPM 2021–2023) show that chemistry consistently ranks below biology and physics in student performance (Lembaga Peperiksaan, 2022, 2023, 2024). One of the key contributing factors is the difficulty students face in comprehending abstract and microscopic topics such as Matter and Atomic Structure, which require an understanding of subatomic particles, electron configurations, and symbolic representations. Students often struggle to integrate the three levels of chemical understanding namely macroscopic, submicroscopic, and symbolic which hinders holistic comprehension and contributes to widespread misconceptions (Azizoglu et al., 2022; Mohd Baharuddin & Karpudewan, 2023; Nkadimeng & Ankiewicz, 2022).

These challenges highlight the need for a paradigm shift in how chemistry is taught. Traditional teacher-centered methods are insufficient to address the complexities of chemistry learning. In response, there is increasing global interest in innovative, student-centered pedagogies that integrate digital technologies. Among these, game-based learning has shown strong potential to enhance engagement, improve academic achievement, and support independent learning (Baltezarević & Baltezarević, 2025; Kucher, 2021; Morris et al., 2025).

To address the challenges in chemistry education and harness the benefits of game-based learning, a Game-Based Chemistry Learning Module, known as KimCraft, was developed. This module integrates Minecraft Education into the teaching of Matter and Atomic Structure and is designed to improve academic performance, foster positive attitudes toward chemistry, and support the development of self-directed learning skills (Sankar & William Benjamin, 2023). However, prior to classroom implementation, the module must undergo a thorough validation process to ensure its design, content, and instructional strategies are accurate, engaging, and aligned with curriculum objectives (Mohamed Abdelmohsen, 2020).

In addition to these design models, KimCraft is underpinned by Social Constructivism Theory. This theory emphasizes that knowledge is constructed through meaningful social interactions. A key concept in this theory is the Zone of Proximal Development (ZPD), which refers to the conceptual space between what a learner can do independently and what they can achieve with the support of a More Knowledgeable Other (MKO) (Mishra, 2023). KimCraft supports scaffolding by offering structured challenges and collaborative missions in Minecraft, where students work in teams to build models, solve chemistry-related problems, and create digital portfolios. These activities situate learning within the students' ZPD, thereby fostering cognitive development through active participation. The multiplayer features of Minecraft Education also enhance collaborative learning by allowing students to construct chemical structures and solve chemistry challenges together, thereby promoting accountability, social

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engagement, and deeper understanding (Furukado et al., 2024; Goh, 2023).

Research Objective

The objective of this article is to determine the validity of the Game-Based Chemistry Learning Module.

RESEARCH METHODOLOGY

Module development

This study adopted the ADDIE instructional design model (Branch, 2009) as the primary framework to guide the development of a game-based chemistry learning module, KimCraft, using the Minecraft Education platform. The ADDIE model consists of five iterative phases, namely Analysis, Design, Development, Implementation and Evaluation, which together provide a structured and systematic approach to instructional design, as summarised in Table 1.

In addition to the ADDIE model, the development of KimCraft was also informed by two complementary frameworks: The Constructive Alignment Model (Biggs, 2003, 2014) and the Form Four Chemistry Curriculum and Assessment Standards Document (DSKP) (Kementerian Pendidikan Malaysia, 2018). These frameworks ensure that the module is pedagogically sound, aligned with the intended learning outcomes, and consistent with current national curriculum requirements.

Table 1. Summary of ADDIE Model Phases in the Development of the KIMCRAFT Chemistry Learning Module

ADDIE Model Phases	Explanation
Analyse	Conducted a literature review and the teacher needs analysis. Surveys and interviews were used to identify key issues in chemistry instruction. The focus was placed on the topic of Matter and Atomic Structure, which was identified as an abstract and challenging topic in Chemistry form four. The study also assessed the need for a game-based chemistry learning module, such as Minecraft, to support teaching and learning in this area.
Design	Learning objectives were established based on the Form Four Chemistry Standards- Based Curriculum and Assessment Document (DSKP). Game-based learning strategies were selected to support student engagement and conceptual understanding. Media such as text, graphics, audio, and Minecraft Education were chosen to enhance interactivity and accessibility. Assessment methods included written tests, mini and midi tasks project, and Classroom-Based Assessment rubrics.
Development	Development of a Game-Based Chemistry Learning Module based on four content standards of the topic Matter and Atomic Structure. The module content is organized systematically and structurally according to the four principles of the Constructive Alignment teaching model by Biggs, (2003) namely learning outcomes, learning content, learning activities such as mini or midi project using Minecraft Education, and assessment. The validity of the module was evaluated by nine experts.
Implementation	Teacher training workshop and intervention implementation for 10 weeks.
Evaluation	Formative assessment: pre-test and self-assessment. Summative assessment: post-test and delayed post-test

Continued

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Validation process

The expert validation process of the KimCraft module was conducted during the development phase of the ADDIE model, prior to the implementation of the intervention with students (Branch, 2009). The validation process involved nine expert reviewers with professional backgrounds in chemistry education, educational technology, instructional design, and STEM innovation, as detailed in Table 2. These experts were selected based on clearly defined inclusion criteria, which required formal training and practical experience in relevant fields, including curriculum development and science pedagogy.

A 23-item structured validation checklist was used to validate the content of the KimCraft Module. Items were grouped under five domains: module objectives, content, format and language, presentation, and usability (Mohamed Abdelmohsen, 2020). Experts rated each item on a 5-point Likert scale (Mohd Rokeman, 2024). Items rated 4 or 5 by most reviewers were considered relevant. The data were systematically analyzed to establish expert consensus on the essential elements and necessary improvements required in the KimCraft module. Additionally, qualitative feedback was collected through open-ended comments to identify areas for module refinement.

Table 2. Panel of Experts Involved in the Validation Process

Panel	Designation	Area of Expertise
1	School Improvement Specialist Coaches (SISC+)	Chemistry Education, Innovation
2	Assistant Director, Delivery Specialist Malaysia Education Blueprint, Educational Policy Planning and Research Division (EPRD), Kementerian Pendidikan Malaysia.	Chemistry Education, STEM Education Design and Development Research (DDR)
3	Senior Lecturer Institute of Teacher Education (IPG)	Chemistry Education
4	School Improvement Specialist Coaches (SISC+)	Digital Curriculum, Module Development, Innovation
5	Head of Department, Department of Digital and Information Technology, Institute of Teacher Education (IPG)	Educational Technology
6	Head of Department, Department of Educational Studies, Institute of Teacher Education (IPG)	Educational Technology
7	Head of Department, Department of External and International Relations, Institut Aminuddin Baki	STEM Education, Innovation
8	School Improvement Specialist Coaches (SISC+)	STEM Education
9	Senior Science and Mathematics Teacher (GKSM)	STEM Education, Module Development

The validation process employed the Content Validity Index (CVI) as suggested by Polit et al., (2007). Each expert evaluated the appropriateness of every item in the module using a five-point Likert scale, ranging from “1” (Strongly Disagree) to “5” (Strongly Agree) (Mohd Rokeman, 2024). Items were considered relevant when most experts assigned a rating of “4” or “5”. The content validity of the module

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was then calculated using CVI, which measures the degree of agreement among experts. For item-level content validity (I-CVI), scores were dichotomized as 0 for non-relevant and 1 for relevant, with an acceptable minimum value of 0.78 when more than three experts are involved. The overall scale content validity (S-CVI) was also calculated, with 0.80 set as the minimum threshold for acceptance. This validation ensured that each item accurately reflected the intended constructs and was aligned with the objectives of the developed module. After the evaluation, both I-CVI and S-CVI values were analyzed to determine the overall content validity of the KimCraft module.

RESEARCH FINDINGS

The findings revealed that the experimental group achieved significantly higher scores in programming compared to the control group, $t(58) = -4.77$, $p < .01$. Similarly, their attitudes toward programming improved considerably after the intervention, $t(58) = -3.83$, $p < .01$. In terms of knowledge retention, the experimental group was able to sustain their learning more effectively than the control group, $t(58) = -5.86$, $p < .01$. However, no significant difference was found between the groups in attitude retention, as both showed only slight improvements when they returned to conventional instruction.

DISCUSSION

The findings confirm that combining PBL with metaverse environments significantly improves learning outcomes in programming. The positive effects on achievement and retention align with research showing that immersive learning supports knowledge transfer and long-term memory (Moreno, 2012; Duan et al., 2021). Short-term improvements in attitudes support the claim that PBL enhances motivation and engagement (Kokotsaki et al., 2016; Jaaffar & Adnan, 2025). However, the lack of sustained attitude differences suggests that without continuous innovative practices, motivational gains diminish once conventional methods resume. Similar observations were made by Hew and Cheung (2014), who reported that student enthusiasm declines if innovative pedagogy is not maintained consistently. Theoretically, this study supports Bruner's (1966) model of representation, where the metaverse provided concrete and visual stages (enactive and iconic) before transitioning to symbolic coding activities (Hong & Kanaparan, 2024). Practically, these results highlight the value of immersive digital tools in cultivating 21st-century competencies such as collaboration, creativity, and critical thinking skills emphasized in Malaysia's educational transformation.

CONCLUSION

This research provides empirical evidence that PBL, when delivered in a metaverse environment, can significantly enhance programming achievement, retention, and short-term attitudes among secondary students. While findings confirm the pedagogical potential of the metaverse, sustaining motivation requires ongoing innovation beyond isolated interventions. This study demonstrates that integrating Project-Based Learning (PBL) within a metaverse environment significantly enhances secondary students' programming achievement, knowledge retention, and short-term attitudes toward programming. By embedding learning in immersive and collaborative virtual contexts, metaverse-based PBL supports deeper conceptual understanding and sustained cognitive engagement, consistent with prior research highlighting the effectiveness of PBL and immersive technologies in complex STEM learning (Thomas, 2000; Kokotsaki et al., 2016; Duan et al., 2021; Jaaffar & Adnan, 2025). The findings also align with Bruner's (1966) Cognitive Learning Theory, where learning progresses from concrete and visual representations to symbolic abstraction an instructional sequence well supported by metaverse affordances in programming education (Hong & Kanaparan, 2024). However, the absence of significant differences in attitude retention indicates that motivational benefits may diminish when innovative pedagogies are discontinued, reinforcing evidence that sustained instructional innovation is essential for long-term affective outcomes (Hew & Cheung, 2014). Educational policymakers and curriculum developers should consider incorporating metaverse-supported PBL into national instructional guidelines, teacher professional development programs, and digital infrastructure planning to better align programming education with 21st-century skill demands. Future research should extend retention periods, employ randomized designs and integrate qualitative insights to inform scalable and sustainable policy-driven implementation of immersive learning in secondary education.

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