ADVANCING 21ST-CENTURY SCIENCE LEARNING THROUGH THE *ELEMENT EXPLORER* INTERACTIVE E-MODULE: DEVELOPMENT AND USABILITY EVIDENCE

[1]Muhd Afiq Iqbal Zainal, [2]Ahmad Muslihin Ahmad*
[1,2]Biology Department, Faculty of Science and Mathematics,
Universiti Pendidikan Sultan Idris, 35900 Tanjong Malim, Perak, Malaysia

*[1]afiqiqbalzainal16@gmail.com, [2]muslihin@fsmt.upsi.edu.my**

ABSTRACT

This study reports the development and usability evaluation of Element Explorer, an interactive e-learning module designed to address the challenges students face in mastering abstract science concepts, particularly the periodic table and electron configuration, in the Form Four curriculum. Guided by the ADDIE instructional design model (Analysis, Design, Development, Implementation, and Evaluation), the module integrated multimedia elements such as animations, quizzes, and interactive navigation to enhance engagement and comprehension. Quantitative design was employed using the adapted USE Questionnaire (Lund, 2001), with responses obtained from 76 science-stream students from Slim River, Perak. Validity testing confirmed strong face validity (100% for the module; 98.3% for the instrument) and excellent content validity (CVI = 1.00), while reliability analysis yielded a Cronbach's alpha of 0.93. Descriptive results indicated high usability across four constructs—usefulness, ease of use, satisfaction, and ease of learning (M = 3.74, SD = 0.43). Students highlighted the module's intuitive interface and interactivity as key factors supporting self-directed learning and improving their understanding of abstract chemistry concepts. The findings demonstrate that Element Explorer is a valid and usable alternative teaching tool that complements 21st-century learning goals. Implications extend to the diversification of science teaching practices, integration of digital curriculum innovations, and future research on long-term learning outcomes in broader educational contexts.

Keywords: Interactive E-Module, Science Education, Periodic Table, Usability, ADDIE Model, 21st-Century Learning

INTRODUCTION

Science education is widely regarded as essential for national development and global competitiveness. It equips learners with critical skills in reasoning, problem-solving, and innovation, which are increasingly important in an era defined by rapid technological and scientific advancement. In Malaysia, the Malaysia Education Blueprint 2013–2025 emphasizes the development of scientific literacy and higher-order thinking skills as fundamental educational outcomes (Ministry of Education Malaysia, 2013). Despite these aspirations, students frequently encounter significant challenges in mastering abstract scientific concepts, particularly in chemistry.

Among the most difficult topics for secondary students are the periodic table and atomic structure. These concepts require the mental visualization of subatomic particles such as protons, neutrons, and electrons, as well as their arrangements and interactions. National and international studies report persistent misconceptions and low achievement levels. In Malaysia, 40% to 55% of students struggle to explain periodic trends or relate them to physical and chemical properties (Chew et al., 2020; Mandasari et al., 2021). Similar learning difficulties

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have been reported in Indonesia, Spain, and other countries (Ningsih et al., 2020; Alvarez-Herrera, 2021).

Traditional science instruction remains heavily reliant on teacher-centered delivery and textbook-based explanations. While such methods provide foundational knowledge, they often lack the visual and interactive elements required to support students' understanding of abstract content. This is especially problematic in chemistry, where students frequently fail to construct mental models of atomic structures or periodic relationships (Rinaldi et al., 2022). Without effective scaffolding, student engagement and long-term retention suffer, limiting progression to more advanced topics such as chemical bonding and electrochemistry.

Emerging digital technologies offer promising solutions. Interactive modules, multimedia simulations, and educational games have been shown to enhance motivation, conceptual understanding, and knowledge retention (Wang et al., 2014; Issa et al., 2011). In Malaysia, mobile apps such as SPATO and virtual labs have been well-received by students and teachers for improving chemistry comprehension (Ang et al., 2018); (Lestarani et al., 2023). Similar outcomes have been reported with gamified tools like Chem Ball, Science Kingdom, and augmented reality applications, which support active learning and improve usability scores among high school students (Wijaya et al., 2025; Silva & Sousa, 2024); (Nurpandi & Gumelar, 2018).

These innovations are informed by constructivist theories of learning, which argue that students actively construct knowledge through exploration and reflection (Piaget, 1972; Vygotsky, 1978). Connectivism, proposed by Siemens (2005), emphasizes the role of digital networks in facilitating learning across various platforms. Mayer’s (2001) Cognitive Theory of Multimedia Learning further suggests that learning is maximized when verbal and visual inputs are integrated while managing cognitive load. Collectively, these theories support the use of multimedia and interactive elements in digital chemistry education.

Instructional design models such as ADDIE (Analysis, Design, Development, Implementation, and Evaluation) offer a systematic approach to developing digital learning materials that are both pedagogically sound and empirically validated (Branch, 2009). Numerous studies have applied ADDIE successfully in developing chemistry-focused e-learning tools that enhance both usability and content validity (Ismail et al., 2021). However, despite the growing body of international research, few studies in Malaysia have systematically validated the usability of such tools for abstract chemistry topics such as atomic structure and the periodic table.

This study addresses that gap by developing and evaluating Element Explorer, an interactive e-module designed for Form Four students in the Malaysian secondary curriculum. The objectives are (i) to develop a content-valid and instructionally sound e-module on the topic Elements and Materials, and (ii) to evaluate its usability based on usefulness, ease of use, satisfaction, and ease of learning. By integrating learning theory with structured instructional design, this research aims to contribute meaningful solutions to longstanding challenges in chemistry education.

METHODOLOGY

Research Design

This study employed a developmental research design grounded in the ADDIE instructional model, which comprises the phases of Analysis, Design, Development, Implementation, and Evaluation. The ADDIE model was selected for its systematic and iterative process, ensuring that instructional materials align with learner needs, curricular goals, and sound pedagogical strategies. Its effectiveness in the development of validated learning resources is well established in the instructional design and chemistry education literature (Branch, 2009; Molenda, 2015; Lay & Osman, 2018; Aris, 2024). To assess usability, the study incorporated a quantitative descriptive approach, consistent with best practices in usability research that call for empirical validation of digital interventions (Hornbæk, 2006; Lewis, 2018).

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Participants

Participants consisted of 76 Form Four science-stream students from a public secondary school in Slim River, Perak, Malaysia. They were purposively sampled from a cohort of 95 students who had previously completed the Elements and Materials topic. All participants were aged 16, the standard for Form Four. The sample size exceeded the recommended range of 30–50 for usability testing, increasing representativeness and ecological validity (Sauro & Lewis, 2012).

Development of the Element Explorer E-Module

The intervention was an interactive e-module titled Element Explorer, designed for the Form Four science syllabus in the Kurikulum Standard Sekolah Menengah (KSSM). It focused on subtopics such as the periodic table, classification of elements, and electron configuration areas widely acknowledged as challenging (Chew et al., 2020); (Mandasari et al., 2021).

The module was developed based on Mayer's Cognitive Theory of Multimedia Learning (Mayer, 2009), incorporating dual coding and minimizing cognitive overload. It also integrated principles from constructivism and connectivism to promote active, exploratory, and networked learning (Piaget, 1972; Siemens, 2005). Features included animations, interactive quizzes, and intuitive navigation tailored for diverse learning styles. Prior studies have shown such features to significantly enhance usability and engagement in science education (Adnan et al., 2022; Mahanan et al., 2021). Two prototyping cycles were conducted with input from subject-matter experts to refine the module's accuracy, clarity, and instructional design.

Instruments

Two primary instruments were used: the Element Explorer module and an adapted version of Lund's (2001) USE Questionnaire. The latter measured four usability dimensions: usefulness, ease of use, satisfaction, and ease of learning. It has been widely validated in educational technology contexts, including in Malaysia (Fauzi et al., 2021).

The questionnaire was translated into Bahasa Malaysia and simplified for secondary-level comprehension. Content validity was assessed by three experts, yielding a CVI of 1.00 (Polit & Beck, 2006). Face validity checks showed 100% agreement on module relevance and 98.3% agreement for the questionnaire. A pilot test with 19 students (not included in the final sample) resulted in Cronbach's alpha of 0.93, exceeding the 0.70 benchmark (Nunnally & Bernstein, 1994).

Procedure

All ADDIE phases were implemented sequentially but iteratively:

i. *Analysis*: Included curriculum review, student performance data analysis, and interviews with teachers confirming students' difficulties with periodicity and atomic structure.
ii. *Design*: Included SMART learning objectives, a multimedia-integrated storyboard, and formative assessments.
iii. *Development*: Used digital authoring tools; expert feedback led to two refinement cycles, as recommended by best practices in Malaysian module design (Lay & Osman, 2018).
iv. *Implementation*: Took place over two weeks during science lessons, including teacher-facilitated sessions and independent use.
v. *Evaluation*: Included the usability questionnaire and open-ended feedback.

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Data Collection and Analysis

Quantitative data from the USE questionnaire were analyzed using IBM SPSS Statistics version 27. Each item used a 4-point Likert scale (1 = strongly disagree to 4 = strongly agree). Descriptive statistics (means and standard deviations) were computed. Based on Riduwan (2012), mean scores were interpreted as low (1.50–2.49), moderate (2.50–3.49), or high (3.50–4.00) usability. Standard deviations were interpreted as very low (0.00–0.24) to very high (0.75–1.00). Cronbach's alpha for the final dataset confirmed internal reliability.

RESULTS

This study reports findings in three major dimensions: instrument validation, reliability analysis, and usability evaluation of the Element Explorer interactive e-module. The triangulated evidence supports the claim that the module is both pedagogically valid and highly usable for enhancing student understanding of abstract scientific concepts, particularly in chemistry education.

Validity and Reliability of Instruments

Validation through expert review yielded strong evidence of both face and content validity. Face validity analysis revealed complete agreement among experts, with 100% approval for the module's visual and pedagogical design, and 98.3% agreement on the clarity and relevance of the questionnaire items. This confirms the module's appropriateness for secondary-level science learners, aligning with best practices in digital instructional design validation (Martin et al., 2020).

The content validity index (CVI) achieved a perfect score (CVI = 1.00), signifying unanimous expert consensus on the relevance, accuracy, and curriculum alignment of both the module content and the evaluation instrument. These findings are consistent with established literature that underscores the role of expert validation in ensuring alignment between digital learning tools and curricular objectives (Chiu & Churchill, 2016; Baco & Ishak, 2021).

Reliability analysis further supported these results. The adapted USE Questionnaire produced a Cronbach's alpha coefficient of 0.93, exceeding the accepted threshold of 0.70 for high internal consistency (Nunnally & Bernstein, 1994; Gliem & Gliem, 2003. This suggests that the instrument reliably measures usability constructs in a coherent and stable manner. Comparable reliability metrics have been reported in studies assessing interactive e-learning tools in science education contexts (Lund, 2001); (Suraya & Caseley, 2017; Al-Rahmi et al., 2018).

Usability Evaluation

Table 1 summarizes the descriptive statistics for the four usability constructs evaluated in the study.

Table 1.

Mean and Standard Deviation of Usability Constructs (N = 76)

Construct	Mean (M)	SD	Interpretation
Usefulness	3.72	0.438	High
Ease of Use	3.74	0.438	High
Satisfaction	3.77	0.406	High
Ease of Learning	3.73	0.439	High
Overall	3.74	0.430	High

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All four usability dimensions received high scores, with the overall mean usability rating reaching 3.74 (SD = 0.430). Among the constructs, *satisfaction* had the highest mean (M = 3.77), indicating a positive emotional response to the module's interface and interactivity. This echoes prior findings that learner satisfaction is a critical determinant of sustained engagement with educational technologies (Issa et al., 2011; Ting et al., 2020).

Similarly, high scores for *ease of use* (M = 3.74) and *ease of learning* (M = 3.73) reflect the module's user-friendly design and its ability to facilitate autonomous learning. These outcomes align with Mayer's Cognitive Theory of Multimedia Learning, which posits that interactive and well-structured multimedia can reduce cognitive load and enhance knowledge construction (Mayer, 2009; Cheng & Yeh, 2019).

Students noted that the animations, quizzes, and visualizations helped demystify abstract chemistry concepts like electron configuration. This finding is consistent with research demonstrating that visual scaffolding in digital environments significantly enhances understanding in chemistry education (Wu & Puntambekar, 2012; Chew et al., 2020; Mandasari et al., 2021).

The construct of *usefulness* (M = 3.72) also received a high rating, suggesting that students perceived the module as beneficial to their academic learning. This supports global findings showing that interactive and contextually relevant digital tools enhance both engagement and academic performance in science education (Wang et al., 2014; Tsai et al., 2020; Ali et al., 2022).

DISCUSSION

The triangulated evidence across validity, reliability, and usability dimensions positions the Element Explorer module as a rigorously evaluated innovation in science education. Unlike many digital tools that are deployed without empirical scrutiny, this module underwent systematic validation and demonstrated strong user acceptance. This supports the argument that applying instructional design models such as ADDIE can result in educational technologies that are both pedagogically sound and engaging for learners (Branch, 2009; Ismail et al., 2021)

This study also reinforces the expanding body of research suggesting that well-designed multimedia tools can address persistent conceptual difficulties in chemistry education. Regional and international studies report consistent gains in motivation, comprehension, and conceptual retention through interactive modules (Abdelrahman et al., 2020; Alvarez-Herrera, 2021; Salina & Aisyah, 2024). By contributing localized data from Malaysia, this study extends global trends and demonstrates the universal applicability of multimedia principles in secondary science contexts.

Nevertheless, the study's scope must be acknowledged. While the findings provide robust evidence of usability and validation, direct learning outcomes were not measured. Thus, conclusions regarding effectiveness must be inferred rather than empirically confirmed. Future research should include quasi-experimental designs incorporating pre- and post-tests to measure actual learning gains, retention, and long-term knowledge transfer.

CONCLUSION

This study developed and systematically evaluated Element Explorer, an interactive e-module designed to support the teaching and learning of the Form Four Chemistry topic Elements and Materials. Through rigorous validation processes, the module demonstrated strong face and content validity, high reliability, and consistently positive usability ratings across the constructs of usefulness, ease of use, satisfaction, and ease of learning. These results indicate that the module is not only pedagogically sound but also well aligned with the expectations of 21st-century learners.

The findings provide three key contributions. First, they confirm that applying structured instructional design frameworks such as ADDIE, informed by constructivist and multimedia learning theories, can result in digital tools that effectively support the comprehension of

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abstract scientific concepts. Second, the study adds localized empirical evidence from Malaysia, complementing the international literature on the value of interactive multimedia in chemistry education. Third, the research highlights the importance of usability as a prerequisite for adoption, demonstrating that student satisfaction, intuitive navigation, and perceived usefulness are critical to the sustained integration of digital modules in secondary classrooms.

The implications are multifold. For teachers, Element Explorer offers a validated digital resource that diversifies pedagogical strategies, enhances student engagement, and supports independent learning. For curriculum developers and policymakers, the study underscores the potential of systematically designed e-modules to advance national goals of digital innovation and scientific literacy. At the same time, the limitations of this study must be acknowledged: the evaluation focused primarily on usability, without measuring direct learning outcomes such as achievement gains or long-term retention.

Future research should therefore expand the scope by incorporating experimental or longitudinal designs that assess learning effectiveness, retention, and higher-order skills. Cross-school implementations and integration with emerging technologies such as augmented reality or adaptive learning platforms may further extend the impact of digital modules in science education.

In conclusion, the Element Explorer e-module stands as a promising innovation that bridges theory and practice in digital science pedagogy. Its strong validation outcomes demonstrate its readiness for classroom adoption, while its potential for scalability positions it as a meaningful contribution to both local and international efforts to transform science education through technology.

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