Journal of Chemical Learning Innovation
Vol. 3, No. 1, June 2026, pp. 32~40
ISSN: 3063-0886, DOI:10.37251/jocli.v3i1.2968

Development and Validation of Multimedia-Based Interactive Learning Media to Enhance Students' Conceptual Understanding of the Periodic Table in Chemistry Education

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Article Info

Article history:

Received Jan 21, 2026
Revised Feb 17, 2026
Accepted Mar 21, 2026
OnlineFirst Apr 1, 2026

Keywords:

Chemistry Education
Conceptual Understanding
Interactive Learning
Multimedia Learning Media
Periodic Table

ABSTRACT

Purpose of the study: This study aims to develop and validate multimedia-based interactive learning media to enhance students' conceptual understanding of the periodic table in chemistry education.

Methodology: The research employed a Research and Development (R&D) approach using the ADDIE model, which includes analysis, design, development, implementation, and evaluation stages. The developed media integrates text, images, animations, and interactive features to facilitate meaningful learning experiences.

Main Findings: The results of expert validation indicate that the media is highly valid, with an average score of 87.5% from media experts and 90.0% from subject matter experts. The implementation results show positive student responses, with an average score of 88.25%, indicating high levels of engagement and usability. Furthermore, the effectiveness test reveals a significant improvement in students' conceptual understanding, as indicated by an increase in post-test scores and a moderate N-gain of 0.58.

Novelty/Originality of this study: Novelty of this study lies in the integration of interactive multimedia features with a systematic validation process, specifically designed to address conceptual challenges in learning the periodic table. This study provides an innovative and empirically validated learning solution that contributes to improving the quality of chemistry education.

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1. INTRODUCTION

The rapid advancement of science and technology, particularly in information and communication technologies, has significantly transformed various aspects of human life, including education [1]-[3]. In the context of chemistry education, this transformation demands the integration of innovative instructional strategies that leverage digital tools to enhance teaching and learning processes [4]-[6]. Teachers are no longer expected to function merely as transmitters of knowledge but as facilitators who design meaningful and engaging learning experiences [7]. Consequently, the use of interactive multimedia-based learning media has become increasingly relevant as it enables the delivery of complex scientific concepts in more accessible and dynamic ways.

Instructional media plays a crucial role in shaping students' learning experiences and outcomes [8]-[10]. The integration of multimedia elements such as text, images, animations, audio, and simulations can stimulate multiple sensory channels, thereby improving students' engagement and comprehension [11], [12]. Compared to traditional teaching methods, multimedia-based learning environments provide opportunities for active learning, allowing students to visualize abstract concepts and interact with content more effectively [13]-[15]. As a result, such approaches are considered particularly suitable for subjects like chemistry, which often involve abstract and symbolic representations.

Despite the recognized benefits of multimedia integration, the implementation of interactive learning media in chemistry classrooms remains limited. Observations in educational settings indicate that many teachers still rely on conventional instructional approaches, such as lectures and textbook-centered teaching, with minimal use of digital or interactive resources. This reliance on traditional methods often leads to passive learning environments, where students have limited opportunities to explore concepts independently. Consequently, students' conceptual understanding tends to be superficial, and their motivation to learn chemistry decreases over time.

One of the fundamental topics in chemistry education that presents significant learning challenges is the periodic table of elements [19], [20]. The periodic table is a core concept that organizes chemical elements based on their properties and atomic structure, serving as a foundation for understanding various chemical phenomena. However, students frequently perceive this topic as difficult due to the large amount of information involved, including element symbols, atomic numbers, periodic trends, and group classifications. Without appropriate instructional support, students often resort to rote memorization rather than developing a deep conceptual understanding.

The conventional presentation of the periodic table in classrooms typically in the form of static charts or textbooks further exacerbates these challenges [21-[23]. Such representations often lack interactivity and contextual information, making it difficult for students to explore relationships among elements or visualize periodic trends [24]-[26]. As a result, students may struggle to connect theoretical knowledge with practical applications, leading to fragmented understanding. This issue highlights the need for more effective instructional media that can transform abstract chemical concepts into meaningful learning experiences.

Previous studies have demonstrated the potential of multimedia-based learning tools in improving students' engagement and learning outcomes in science education [29], [30]. However Yanto & Sari [15] many of these studies primarily focus on general multimedia usage without emphasizing interactivity or rigorous validation processes. Furthermore, limited research has specifically addressed the development and validation of interactive multimedia learning media tailored to the periodic table topic in chemistry education [29]. This indicates a clear research gap in designing empirically tested instructional media that not only attract students' attention but also effectively enhance their conceptual understanding.

In response to these challenges, this study introduces a novel approach by developing and validating multimedia-based interactive learning media specifically designed for the periodic table. The novelty of this research lies in its integration of interactive features such as clickable elements, animations, and immediate feedback with a systematic validation process involving expert judgment and empirical testing. This approach ensures that the developed media is not only engaging but also pedagogically sound and aligned with learning objectives in chemistry education.

Therefore, this study is urgently needed to address the limitations of conventional teaching methods and to provide an effective solution for improving students' conceptual understanding of the periodic table. By developing and validating an interactive multimedia learning medium, this research aims to contribute to the advancement of chemistry education practices and to support teachers in implementing more innovative and student-centered learning strategies. Ultimately, the findings of this study are expected to enhance the quality of chemistry instruction and foster deeper conceptual learning among students.

2. RESEARCH METHOD

2.1. Research Design

Study employed a Research and Development (R&D) approach aimed at producing and validating a multimedia-based interactive learning medium to enhance students' conceptual understanding of the periodic table. The R&D approach was selected because it systematically integrates the processes of product design, development, validation, and evaluation to ensure both pedagogical and practical effectiveness [30]-[32]. The development procedure in this study was adapted from a simplified ADDIE model (Analysis, Design, Development, Implementation, and Evaluation), which is widely used in educational technology research due to its systematic and iterative nature [33]-[35]. The use of this model ensures transparency in each stage of development and allows continuous refinement of the product based on expert and user feedback.

Before presenting the development stages, the following table outlines the overall structure of the research design.

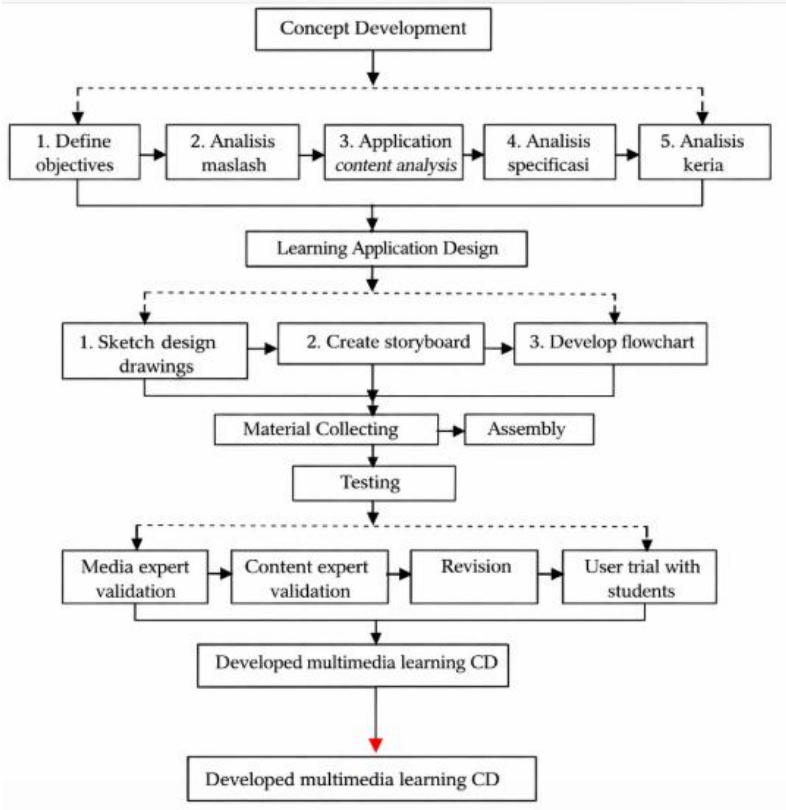

Figure 1. Research Design Framework Based on ADDIE Model

As shown in Table 1, the research design emphasizes iterative refinement, ensuring that the developed media meets both content and technical quality standards.

2.2. Development Procedure

The development process began with the analysis phase, where classroom observations and preliminary studies were conducted to identify key problems in teaching the periodic table. This phase also included curriculum analysis and identification of students' learning difficulties, particularly related to abstract chemical concepts. In the design phase, the structure of the multimedia learning media was carefully planned. This included the preparation of learning objectives, development of content outlines, creation of storyboards, and construction of navigation flowcharts [36], [37]. The design ensured that the media would be interactive, visually engaging, and aligned with chemistry learning outcomes.

The development phase involved the actual production of the multimedia content using appropriate software tools. Various elements such as animations, interactive buttons, audio explanations, and visual representations of the periodic table were integrated into a cohesive learning application. At this stage, the initial prototype was produced and prepared for validation.

The implementation phase consisted of a limited trial conducted with students to examine usability, engagement, and clarity of the media. Finally, the evaluation phase involved expert validation and revisions based on feedback to ensure the quality and effectiveness of the final product.

2.3. Research Subjects and Sampling Technique

The subjects of this study consisted of three groups: media experts, subject matter experts, and students. Media experts were selected based on their expertise in educational technology and multimedia design, while subject matter experts were chemistry educators with strong competence in the periodic table topic.

The student participants were Grade X students from a vocational high school who were currently studying the periodic table topic. The sampling technique used in this study was purposive sampling, as participants were selected based on their relevance to the research objectives. To provide a clear overview of the participants involved, the distribution of research subjects is presented in the following table.

Table 1. Research Subjects

Participant Group	Criteria	Number
Media Experts	Multimedia/educational technology	2
Subject Matter Experts	Chemistry teachers/lecturers	2
Students	Grade X students studying periodic table	30

As indicated in Table 1, the inclusion of different participant groups ensured comprehensive evaluation from both expert and user perspectives.

2.4. Research Instruments

Data in this study were collected using several instruments, including validation questionnaires, student response questionnaires, and conceptual understanding tests. The validation instruments were designed using a Likert scale to assess the quality of the media in terms of content accuracy, instructional design, interactivity, and technical aspects. The conceptual understanding test was developed to measure students' mastery of periodic table concepts before and after using the media. Meanwhile, the student response questionnaire aimed to capture students' perceptions regarding usability, attractiveness, and effectiveness of the developed media.

To clarify the components assessed in the validation process, the instrument indicators are summarized in the following table.

Table 2. Validation Instrument Indicators

Aspect	Indicators
Content Quality	Accuracy, relevance, completeness of material
Instructional Design	Clarity of objectives, learning flow, feedback
Media Design	Visual appearance, interactivity, navigation
Technical Quality	Functionality, accessibility, responsiveness

The use of these instruments ensured that both pedagogical and technical dimensions of the media were systematically evaluated. Validation process was conducted in two stages: expert validation and empirical testing. Expert validation involved both media experts and subject matter experts who assessed the product using the prepared validation instruments. Their feedback was used to revise and improve the media before implementation. After expert validation, a limited trial was conducted with students to evaluate the practicality and effectiveness of the media. Students interacted with the media during the learning process and subsequently provided feedback through questionnaires and test results.

2.5. Data Analysis Techniques

Data analysis in this study employed both quantitative and qualitative approaches. Quantitative data obtained from validation questionnaires and student responses were analyzed using descriptive statistics, specifically mean scores and percentage calculations. The level of validity was determined based on predefined criteria. To interpret the validation results, the following criteria were used:

Table 3. Validity Criteria

Score Range	Category
81–100%	Very Valid
61–80%	Valid
41–60%	Moderately Valid
21–40%	Less Valid
0–20%	Invalid

As shown in Table 3, the categorization provides a clear benchmark for determining the feasibility of the developed media. Furthermore, the effectiveness of the media in improving students' conceptual understanding was analyzed using pre-test and post-test scores, which were then compared to determine learning gains. Qualitative data from expert suggestions and student feedback were analyzed descriptively to support the quantitative findings and guide revisions.

Overall, this methodology ensures transparency, validity, and reliability through systematic development stages, multi-source validation, and comprehensive data analysis. The integration of expert judgment and empirical testing strengthens the credibility of the developed multimedia learning media, making it suitable for enhancing students' conceptual understanding of the periodic table in chemistry education.

3. RESULTS AND DISCUSSION

The development of the multimedia-based interactive learning media followed the ADDIE model. The final product consisted of an interactive application integrating text, images, animations, audio explanations, and clickable elements representing each chemical element.

The media included several main features: (1) interactive periodic table navigation, (2) detailed element information, (3) periodic trends visualization, (4) practice quizzes with immediate feedback, and (5) learning summaries. These features were designed to support students' conceptual understanding rather than rote memorization.

Media experts evaluated the product based on visual design, interactivity, navigation, and technical quality. The results of the media expert validation are presented in Table 4.

Table 4. Results of Media Expert Validation

Aspect	Score (%)	Category
Visual Design	88	Very Valid
Interactivity	90	Very Valid
Navigation	85	Very Valid
Technical Quality	87	Very Valid
Average	87.5	Very Valid

As shown in Table 4, the average validation score from media experts reached 87.5%, indicating that the developed media is highly valid and suitable for use with minor revisions. Subject matter experts assessed the accuracy, relevance, and completeness of the chemistry content. The results are summarized in Table 5.

Table 5. Results of Subject Matter Expert Validation

Aspect	Score (%)	Category
Content Accuracy	92	Very Valid
Concept Clarity	89	Very Valid
Relevance to Curriculum	91	Very Valid
Completeness of Material	88	Very Valid
Average	90.0	Very Valid

Based on Table 5, the average score of 90.0% indicates that the content is highly accurate and appropriate, confirming the scientific validity of the developed media.

Following expert validation, several improvements were made, including:

- Enhancing animation smoothness,
- Simplifying explanations of periodic trends,
- Improving navigation consistency,
- Adding more practice questions.

These revisions ensured better usability and conceptual clarity. A limited trial was conducted with 30 students. Their responses to the media were collected through questionnaires.

Table 6. Student Responses to Multimedia Learning Media

Aspect	Score (%)	Category
Attractiveness	89	Very Good
Ease of Use	86	Very Good
Interactivity	88	Very Good
Learning Motivation	90	Very Good
Average	88.25	Very Good

Table 6 shows that students gave a very positive response, with an average score of 88.25%, indicating that the media is engaging, easy to use, and motivating. To strengthen the findings, semi-structured interviews were conducted with selected students. The results are summarized in Table 7.

Table 7. Summary of Student Interview Results

Theme	Student Response
Understanding	"The animations helped me understand periodic trends better."
Engagement	"Learning feels more interesting compared to textbooks."
Difficulty Reduction	"I don't need to memorize everything because I can explore it."
Suggestion	"Add more quiz variations and games."

The interview results indicate that students experienced improved understanding and engagement, particularly due to the interactive and visual features of the media. The effectiveness of the developed media was measured using pre-test and post-test scores. The results are presented in Table 8.

Table 8. Pre-test and Post-test Scores

Test Type	Mean Score
Pre-test	58.4
Post-test	82.7

As shown in Table 5, there was a significant increase in students' scores after using the multimedia learning media. To further analyze effectiveness, the normalized gain (N-gain) was calculated, as presented in Table 9.

Table 9. N-Gain Analysis

N-Gain Score	Category
0.58	Medium

The N-gain score of 0.58 indicates a moderate improvement in students' conceptual understanding. Overall, the results indicate that the developed multimedia-based interactive learning media:

1. Meets high validity standards based on expert evaluation,
2. Receives positive responses from students,
3. Effectively improves students' conceptual understanding of the periodic table.

These findings confirm that integrating multimedia and interactivity in chemistry learning can significantly enhance students' engagement and learning outcomes. The findings of this study demonstrate that the developed multimedia-based interactive learning media is both valid and effective in enhancing students' conceptual understanding of the periodic table in chemistry education. The high validation scores from media experts (87.5%) and subject matter experts (90.0%) indicate that the product meets strong standards in terms of content accuracy, instructional design, and technical quality. These results confirm that a systematically developed multimedia resource can align well with pedagogical principles in chemistry education, particularly when it is designed to support visualization and interactivity. The iterative validation and revision process also ensured that the final product was not only technically functional but also instructionally meaningful.

The positive student responses further reinforce the feasibility of the developed media in real classroom settings. Students reported high levels of engagement, ease of use, and motivation when interacting with the multimedia application. This finding is particularly important in the context of chemistry learning, where students often struggle with abstract concepts and symbolic representations. The integration of animations, interactive features, and immediate feedback appears to have transformed the learning experience from passive reception into active exploration. As a result, students were able to engage more deeply with the periodic table, moving beyond memorization toward conceptual understanding.

In terms of learning effectiveness, the significant increase in post-test scores compared to pre-test scores, along with a moderate N-gain (0.58), indicates that the multimedia-based interactive media contributed meaningfully to students' conceptual improvement. This result suggests that the use of interactive multimedia can facilitate conceptual change by helping students visualize periodic trends, understand relationships between elements, and connect abstract concepts to more concrete representations [38]. In chemistry education, such conceptual gains are crucial because foundational topics like the periodic table underpin more advanced learning in areas such as chemical bonding, reactions, and thermodynamics.

When compared with previous studies, the findings of this research are consistent with existing literature that highlights the benefits of multimedia learning in science education. Prior research has shown that multimedia tools can improve students' engagement and achievement by presenting information through multiple representations [39], [40]. However, Cockerill [41] many earlier studies focused primarily on general multimedia use without emphasizing interactivity or rigorous validation processes. In contrast, this study extends previous work by integrating both interactive design elements and systematic validation, thereby addressing a critical gap in the development of instructional media for chemistry learning.

The novelty of this study lies in its comprehensive approach that combines multimedia integration, interactivity, and empirical validation within a single framework. Unlike conventional multimedia resources that often present static or linear content, the developed media allows students to actively explore the periodic table through clickable elements, animations, and instant feedback mechanisms. This interactive structure supports constructivist learning principles, where students build their own understanding through exploration and engagement. Additionally, the inclusion of both expert validation and student-based evaluation strengthens the credibility of the findings and ensures that the media is both pedagogically sound and practically applicable.

From a pedagogical perspective, the implications of this study are significant for chemistry education. First, it highlights the importance of integrating technology-based learning media to address the abstract nature of chemical concepts. Second, it provides evidence that interactive multimedia can serve as an effective tool to enhance conceptual understanding, not merely as a supplementary resource but as a central component of instruction. Third, the developed media can assist teachers in creating more student-centered learning environments, where learners are encouraged to actively engage with content rather than passively receive information. This aligns with current educational trends that emphasize digital literacy, active learning, and meaningful knowledge construction.

Despite its contributions, this study has several limitations that should be acknowledged. The implementation of the media was limited to a relatively small sample of students from a single educational context, which may affect the generalizability of the findings. Additionally, the study focused primarily on short-term learning outcomes, without examining long-term retention of conceptual understanding. Another limitation is that the effectiveness of the media was not compared with other instructional models or digital tools, which could provide a more comprehensive evaluation of its relative impact. Technical constraints, such as device compatibility and access to technology, may also influence the broader application of the media in different educational settings.

4. CONCLUSION

This study aimed to develop and validate multimedia-based interactive learning media to enhance students' conceptual understanding of the periodic table in chemistry education. The findings indicate that the developed media is highly valid based on expert evaluations and demonstrates strong effectiveness in improving students' conceptual understanding, as evidenced by increased post-test scores and positive student responses. The integration of interactive features, visual representations, and immediate feedback successfully supports meaningful learning and reduces students' reliance on rote memorization. The results confirm that multimedia-based interactive learning media can serve as an effective instructional tool in chemistry education, particularly for abstract topics such as the periodic table. The developed media not only facilitates better conceptual comprehension but also increases student engagement and motivation during the learning process. Thus, this study contributes to the growing body of research emphasizing the importance of technology-enhanced learning in science education. Future studies are recommended to implement the developed media in broader educational settings with larger and more diverse samples to improve generalizability. In addition, further research should explore the integration of this media with other pedagogical approaches and examine its long-term impact on students' conceptual retention and higher-order thinking skills.

ACKNOWLEDGEMENTS

The authors would like to express their sincere gratitude to the media experts, subject matter experts, and students who participated in this study for their valuable contributions and feedback. Appreciation is also extended to the school and all parties who supported the implementation of this research.

AUTHOR CONTRIBUTIONS

Conceptualization, W.A.S.; Methodology, W.A.S.; Software, W.A.S.; Validation, W.A.S.; Formal Analysis, W.A.S.; Investigation, W.A.S.; Resources, W.A.S.; Data Curation, W.A.S.; Writing – Original Draft Preparation, W.A.S.; Writing – Review & Editing, W.A.S.; Visualization, W.A.S.; Supervision, W.A.S.; Project Administration, W.A.S.; Funding Acquisition, W.A.S.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

Not applicable

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