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Development of Interactive Animation Media Based on Website for Waste Management Education Using the MDLC Method

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Abstract

Low understanding of waste management among teenagers at Bank Sampah Serumpun Asoka, Singkawang City necessitates innovative and interactive educational media. This study aims to: (1) design and develop a web-based interactive animation using the Multimedia Development Life Cycle (MDLC) method; (2) test functionality using White Box and Black Box Testing; and (3) measure effectiveness through pre-test and post-test evaluation. The developed application, ASOKA DIGITAL, was built using ReactJS and integrates 9 interactive simulation modules, synchronized audio narration, a drag-and-drop waste sorting game, a 30-question quiz, and a gamification system. White Box Testing yielded cyclomatic complexity V(G) between 1 and 8, while all 27 Black Box Testing scenarios produced conforming results. Effectiveness testing with 34 respondents showed a mean score increase from 90.2 (pre-test) to 98.4 (post-test), a 9.1% improvement. Media quality assessment via Likert scale yielded a mean of 4.41 out of 5.00 (88.2%), categorized as Very Good.

Keywords: Interactive Animation; Web-Based Educational Media; Waste Management; MDLC; Gamification

INTRODUCTION

The waste problem is a growing environmental issue in Indonesia. The volume of waste generated continues to increase with population growth and urbanization, while suboptimal management leads to environmental pollution, public health problems, flooding, and ecosystem damage (Fauzi et al., 2024). This requires effective educational efforts, particularly for youth, the next generation responsible for environmental stewardship.

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In Singkawang City, the Serumpun Asoka Waste Bank group plays an active role in community-based waste management. However, based on initial observations and interviews, the level of understanding among its youth members remains relatively low. The educational media used is still conventional and does not utilize interactive digital media, making it less effective in attracting youth learning interest (Mahmudah, 2024).

Several previous studies have developed multimedia-based educational media for waste management, but most are limited to a single type of interaction, such as video, quizzes, or simple games. None have integrated interactive animation, audio narration, visual simulations, evaluation quizzes, and a gamification system into a single web-based platform specifically designed for adolescents (Ardiyanti et al., 2025) (Capandri et al., 2025).

The development of web technology opens up opportunities to develop learning media that can be accessed anytime through a browser without installation. ReactJS, as a modern JavaScript framework, enables the construction of responsive and animation-rich interactive interfaces (Ibnu et al., 2024). Furthermore, the gamification approach has been proven to increase user motivation and engagement in the learning process (Pujianingsih et al., 2024). Therefore, this study developed ASOKA DIGITAL, a web-based interactive animation media using the MDLC method as a means of waste management education for teenagers at the Serumpun Asoka Waste Bank in Singkawang City. The novelty of this research lies in the integration of nine animation simulation modules, synchronized audio narration, drag-and-drop games, evaluation quizzes, and a gamification system in one responsive platform, a complete approach not yet found in previous studies.

LITERATURE REVIEW

Web-Based Learning Media

Web-based learning media utilizes internet technology, allowing materials to be accessed anytime through a browser. Its main characteristics are flexibility, affordability, and the ability to present multimedia in an integrated manner. The use of interactive multimedia, which combines text, images, audio, animation, and interaction, has been shown to significantly increase user comprehension and engagement (Agustino et al., 2023).

Interactive Animation as an Educational Medium

Interactive animation is a moving visual medium that integrates elements of movement, sound, and user interaction to convey information in an engaging manner. In the context of environmental education, animation can visualize invisible processes, such as the impact of

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plastic pollution in the ocean or the composting process of organic waste (Lingga et al., 2024). The use of educational animation has been shown to increase information retention and learning motivation compared to text or static images (Capandri et al., 2025).

Gamification in Learning

Gamification is the application of game design elements (points, levels, badges, leaderboards) in non-game contexts to increase user motivation and engagement. In educational applications, gamification elements such as scores, combos, and rankings have been shown to encourage users to continue interacting with the content and increase engagement time (Pujianingsih et al., 2024).

Multimedia Development Life Cycle (MDLC)

MDLC is a structured and systematic multimedia development model, consisting of six stages: Concept, Design, Material Collecting, Assembly, Testing, and Distribution (Akbar et al., 2025). The selection of MDLC in this study was based on its suitability to the characteristics of the product being developed, namely a web-based interactive multimedia application. Each stage of the MDLC provides clear guidance in media development from planning to distribution.

White Box and Black Box Testing

White Box Testing examines the internal structure and logic of a program. One commonly used technique is Cyclomatic Complexity with the formula V(G) = E − N + 2, where the value of V(G) represents the number of independent paths to be tested (Siakad et al., 2025). The lower the value of V(G), the simpler the program logic. Black Box Testing evaluates the suitability of system functions based on input and output without considering internal code, making it suitable for verifying user functional requirements (Abdillah et al., 2023).

Previous Research

Research on web-based learning media shows that the use of interactive multimedia can increase user engagement and understanding (Agustino et al., 2023). Ardiyanti et al. developed GEMAS digital media based on animated videos for waste sorting education, but did not integrate gamification or direct interaction (Ardiyanti et al., 2025). Nordiansah developed a web-based waste sorting educational game using JavaScript, but did not provide integrated learning materials and evaluation quizzes (Nordiansah, 2025). Capandri et al. showed that interactive animation can increase emotional engagement with environmental issues, but its

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implementation has not focused on community-based waste management education (Capandri et al., 2025). Based on these studies, this study proposes the development of the ASOKA DIGITAL application that integrates nine learning modules, interactive simulations, synchronized audio narration, drag-and-drop games, evaluation quizzes, and a gamification system in one web-based application using ReactJS.

RESEARCH METHODOLOGY

This study used the MDLC method as a media development framework. The research approach was experimental, with pre-tests and post-tests to measure media effectiveness. Data collection techniques included direct observation, in-depth interviews with the management of the Serumpun Asoka Waste Bank, literature review, and questionnaires administered to 34 teenage waste bank members.

MDLC stages

The ASOKA DIGITAL application was developed using the Multimedia Development Life Cycle (MDLC) method, which consists of six stages: Concept, Design, Material Collecting, Assembly, Testing, and Distribution. This method was chosen because it is suitable for developing interactive multimedia applications that integrate text, images, animation, audio, and user interaction in a single learning medium.

Figure 1 shows a flowchart of the Multimedia Development Life Cycle (MDLC) stages used as a reference in the application development process. Each stage is implemented sequentially, starting from identifying user needs to publishing the application for use by the youth of the Serumpun Asoka Waste Bank in Singkawang City.



Figure 1. Flowchart of the Multimedia Development Life Cycle (MDLC) Stages

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The Concept stage was conducted to determine the objectives of media development, the characteristics of the target users, namely the youth of the Serumpun Asoka Waste Bank, and to develop the scope of educational materials on waste management. Next, the Design stage included the storyboard, application navigation structure, user interface, quiz flow, and educational game mechanics.

The Material Collection phase aims to gather all the multimedia assets used in the application, including graphic illustrations from Freepik, background music from Pixabay, and audio narration created using ElevenLabs. These assets are then integrated in the Assembly phase using ReactJS, HTML5, CSS3, JavaScript, and Framer Motion to create an interactive web-based multimedia application.

The testing phase involves white box testing, black box testing, and effectiveness testing using pre-test and post-test methods to ensure the application performs as expected. The final phase is distribution, which publishes the application so it can be accessed through a web browser without requiring installation.

System Requirements Analysis

Table 1 describes the main functional requirements of the ASOKA DIGITAL application based on the results of observations and interviews with the management of the Serumpun Asoka Waste Bank.

Table 1. Functional Requirements of the ASOKA DIGITAL Application

No	Functional Requirements
1	The system displays the loading page, main menu, and navigation between pages.
2	The system displays 9 interactive simulation modules of waste management materials.
3	The system plays synchronized narration audio and displays caption text.
4	The system displays an evaluation quiz (Smart Quiz) with 30 multiple choice questions.
5	The system displays a drag-and-drop based waste sorting game (60 second timer).
6	The system calculates and displays the user's score, combo, and ranking.
7	The system displays the Information, Gallery, and Asoka Serumpun Waste Bank Program popups.

Source: Research Results (2026)

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System Architecture and Implementation

The ASOKA DIGITAL application was developed using a ReactJS-based Single Page Application (SPA) architecture, allowing for dynamic navigation without page reloads. This approach was chosen to improve the application's responsiveness, speed up page navigation, and provide a more interactive learning experience for users.

Figure 2 shows the ASOKA DIGITAL system architecture. Users access the application through a web browser, and all requests are then processed by ReactJS, the primary framework. ReactJS manages the application's four main modules: Educational Materials, Smart Quizzes, Educational Games, and Interactive Simulations. Each module utilizes various multimedia assets such as images, audio narration, and SVG-based illustrations to create engaging and easy-to-understand learning media.



Figure 2. ASOKA DIGITAL Application System Architecture

Table 2. System Implementation Specifications

Component	Technology
Framework	ReactJS
Programming language	JavaScript
Build Tool	Vite
Styling	CSS3
Animation	Framer Motion
Audio	HTML5 Audio API
Browser	Google Chrome
Architecture	Single Page Application (SPA)

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The application implementation is built using a component-based architecture approach, so that each feature is developed as a stand-alone and reusable component. The program structure is divided into three main files: App.jsx as the main component that regulates application navigation, utils.jsx which contains material data, utility functions, and audio management, and simulations.jsx which implements all interactive simulations in each learning material.

To support multimedia delivery, the application implements the useNarrationSync() hook, which synchronizes audio narration with caption text in real time. This mechanism allows users to follow the material simultaneously through visual and audio media, making the learning process more effective and easier to understand.

In addition to being a learning tool, the application also implements a gamification concept to increase user motivation. Every correct answer or success in the game will generate a score and combo that is automatically calculated by the system. At the end of the learning process, the system provides a ranking based on the total score obtained by the user, namely Beginner (0–40), Warrior (41–60), Pro (61–80), Master (81–90), and Legend (91–100). This gamification application is expected to increase user engagement during the learning process.

Overall, the implemented architecture results in an application that is modular, easy to develop, and easy to maintain. This approach also allows for the addition of new materials, simulations, and features during subsequent development without affecting the application's core components.

System Testing

System testing is divided into three approaches: (1) White Box Testing using Cyclomatic Complexity to test the internal logic of three main functions; (2) Black Box Testing to verify the suitability of input-output for all application features; and (3) Effectiveness testing using pre-test and post-test questionnaires for 34 teenage respondents.

RESULTS AND DISCUSSION

ASOKA DIGITAL Application Interface Implementation

The implementation phase resulted in the ASOKA DIGITAL application, which can be run through a web browser on desktop and smartphone devices. The application interface is designed to be simple for teenagers, the primary users. All pages were developed using ReactJS, allowing for quick navigation between menus without reloading the page.

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Figure 3 shows the main menu page of the ASOKA DIGITAL application. This page serves as a navigation center, providing access to the Educational Materials and Smart Quiz menus, as well as supporting menus such as Information, Gallery, and the Waste Bank Program. The interface layout is designed to be simple so users can directly access the desired features.



Figure 3. ASOKA DIGITAL Main Menu Page Display

After selecting the education menu, users are directed to the material selection page. This page displays all learning materials in the form of cards, arranged systematically, making it easy for users to choose the material they need.

Figure 4 shows the material selection page, which consists of nine learning modules. Each module is developed using an interactive multimedia approach that combines text, illustrations, animations, audio narration, and simulations to make the material delivery more engaging.



Figure 4. Material Selection Page Display

Table 3 shows the implementation of each learning module available in the ASOKA DIGITAL application.

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Table 3. Implementation of Learning Modules

Module	Implementation Form
Organic Waste	Composting Simulation
Inorganic Waste	Garbage Type Animation
B3 waste	Hazardous Waste Simulation
Sorting Trash	Drag and Drop Game
The Dangers of Plastic in the Ocean	Marine Pollution Simulation
Reduce	Waste Reduction Animation
Reuse	Reuse Animation
Recycle	Recycling Animation
Flood	Waste Impact Simulation

Of all the available materials, the Ocean Plastic Hazards simulation was chosen as an implementation example because it offers the most comprehensive level of interactivity. This simulation demonstrates changes in marine environmental conditions due to the accumulation of plastic waste through animations, visual illustrations, and audio narration, enabling users to more realistically understand the impacts of pollution.

Figure 5 shows the implementation of the Marine Plastic Hazards simulation, depicting ocean conditions before and after plastic pollution. Users can observe gradual environmental changes, allowing the material to be presented not only in text but also through interactive visualizations.



Figure 5. Simulation Display of the Dangers of Plastic in the Sea

The entire application interface was developed using a component-based architecture approach in ReactJS. Each page is built as a reusable component, ensuring consistent visual structure across content, even when the content and simulations are different. This approach also simplifies application maintenance and the subsequent development of new content.

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Implementation of Games and Quizzes

In addition to providing learning materials, the ASOKA DIGITAL app also features educational games to practice waste sorting. The games are designed using a drag-and-drop mechanism, where users are asked to drag trash objects to the appropriate bins. Each correct answer adds points to the score, resulting in a combo score, which can boost user motivation during the learning process.

Figure 6 shows a screenshot of a drag-and-drop waste sorting game. This game not only trains users' ability to distinguish between types of waste but also provides a more interactive learning experience than conventional presentations.



Figure 6. Drag and Drop Game View

As a learning evaluation stage, the application provides a quiz consisting of thirty multiple-choice questions. The quiz is given after the user has studied all the material and can be used to gauge their level of understanding.

Figure 7 shows the quiz page used as a learning evaluation tool. The system automatically processes each answer and calculates a score based on the number of correct answers.



Figure 7. Quiz Page View

After completing all the questions, the system will automatically calculate a final score and then rank the user based on a predetermined score range: Beginner, Warrior, Pro, Master,

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and Legend. The evaluation results are displayed live, allowing users to determine their level of understanding after using the app.

White Box Testing

White box testing is performed to ensure the application's internal logic is running as designed. Testing focuses on three main functions: navigate(), processDrop(), and handleAnswer(), as they control the application's navigation, educational gameplay, and user response evaluation.

For example, the navigate() function is used as a White Box analysis object. The function's logic flow is represented as a flowgraph to calculate the Cyclomatic Complexity value and determine the independent paths to be tested.

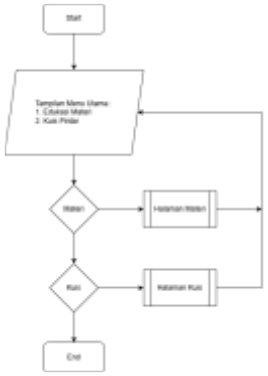


Figure 8. Function Flowgraph (navigate)

Table 4. White Box Test Results

Function	V(G)	Track	Results
navigate()	3	3	All paths executed correctly
processDrop()	8	8	All paths executed correctly
Quiz Logic	3	3	All paths executed correctly

Source: Research Results (2026)

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Based on the test results, all independent paths were successfully executed without any logic errors. Therefore, the application's navigation, gameplay, and evaluation functions are deemed to be working as designed.

Black Box Testing

Black box testing is conducted to ensure all application functions operate according to user requirements. Testing includes the main menu, learning modules, audio narration, educational games, quizzes, and application navigation.

Table 5. Black Box Test Results

No	Tested Features	Expected results	Results
1	Main course	Educational Material Menu, Smart Quiz, Information, Gallery, and Waste Bank Program can be accessed	In accordance
2	Material Module	Materials and simulations are in accordance with the selected module.	In accordance
3	Audio Narration	Audio and captions are displayed according to the material	In accordance
4	Drag and Drop Game	The system processes answers, scores, and notifications correctly.	In accordance
5	Quiz	The system displays the question, calculates the score, and moves to the next question.	In accordance
6	Navigation & Results Page	The system displays the results page and returns to the main menu.	In accordance

The test results show that all the main features can be run according to the predetermined scenario, so that the application is declared to meet functional requirements.

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Media Effectiveness Testing

Effectiveness testing was conducted using pre-test and post-test methods on 34 respondents to determine the increase in understanding after using the ASOKA DIGITAL application.

The test results showed that the average score increased from 90.2 to 98.4, or 9.1%. Although two respondents experienced a decrease in scores, overall, the results indicate that the application is able to improve users' understanding of waste management.

Table 6. Summary of Effectiveness Test Results

No	Information	Pre-Test	Post-Test	Improvement
1	Number of Respondents	34	34	-
2	Average Value	90.2	98.4	+9.1%
3	The highest score	100	100	-
4	Lowest Value	26.7	66.7	+40%



Figure 9. Comparison of Pre-test and Post-test Average Scores.

Media Quality Assessment

Media quality assessment was carried out using a questionnaire that covered aspects of appearance, ease of use, material, and application interactivity.

Table 7. Media Quality Assessment Results

Assessment Aspects	Average value	Category
Interface View	4.45	Very good
Ease of Use	4.38	Very good
Learning materials	4.42	Very good
Application Interactivity	4.40	Very good
Overall Average	**4.41**	**Very good**

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The app received an average score of 4.41, or 88.2%, categorized as Very Good. These results indicate that the app is easy to use, the material is easy to understand, and the interactive features enhance the user's learning experience.

DISCUSSION

The results of this study indicate that ASOKA DIGITAL, a web-based interactive animation media, is effective as a waste management education tool for adolescents. An average increase of 9.1% in the effectiveness test demonstrates that the interactive multimedia-based approach is more successful in increasing understanding than conventional methods currently used. This aligns with previous research that found digital waste education media can significantly improve participants' understanding (Ardiyanti et al., 2025).

The average quality score of 4.41 (Very Good) indicates that the developed interface design, content, and interactions have met user expectations. The waste sorting game aspect received the highest rating (4.71), confirming that the gamification element is the main attraction of this application. This finding is consistent with previous research that gamification in interactive learning significantly increases user motivation (Pujianingsih et al., 2024).

White Box Testing results with a maximum V(G) of 3 for (navigate) and quiz logic indicate that the navigation and evaluation logic are well-designed and easy to test. A V(G) value of 8 for processDrop() reflects reasonable complexity for a function that handles various combinations of trash types and drag-and-drop interactions.

CONCLUSION

Based on the research results, it can be concluded as follows:

1. ASOKA DIGITAL web-based interactive animation media was successfully developed using ReactJS with the MDLC method, integrating 9 interactive simulation modules, synchronized audio narration, a drag-and-drop waste sorting game, a 30-question quiz, and a gamification system with rankings and combos.
2. The White Box Testing results produced V(G) = 1–3 for the navigate() function and quiz logic, and V(G) = 8 for processDrop(). All 27 Black Box Testing scenarios provided Appropriate results with no functional errors found in the application.
3. Media has been shown to be effective in increasing adolescents' understanding by 9.1% (from an average of 90.2 to 98.4 in the post-test). Media quality assessments by 34 respondents yielded an average score of 4.41 out of 5.00 (88.2%), categorized as Very Good.

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SUGGESTION

Based on the research results, it can be concluded as follows:

1. Further research is recommended to expand the scope of respondents to more diverse age groups and different locations so that the effectiveness results are more representative.
2. Cloud-based leaderboard features and user authentication can be added to allow longitudinal tracking of individual learning progress.
3. The content can be enriched with specific modules related to waste management in Singkawang City, such as processing organic waste into compost and recycling inorganic waste.
4. Development into a Progressive Web App (PWA) is recommended so that the application can be installed and accessed offline, expanding reach to areas with limited internet access.

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