Design and Development of Learning Tools Through Web-Based Puzzle Games

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Abstract

The development of digital technology offers significant opportunities for developing interactive learning media for early childhood. Educational games are an effective alternative for improving cognitive abilities because they offer a fun learning process tailored to children's characteristics (Rahayu & Dewi, 2021). One widely used form of interactive media is digital puzzles, which have been shown to stimulate children's thinking skills, concentration, and memory through the gradual activity of assembling visual shapes (Sari & Putra, 2020; Novita & Krissandi, 2021). Furthermore, research shows that educational games designed with interactive mechanisms can significantly improve working memory and focus in elementary school-aged children (Handayani & Rahayu, 2023; Maulana & Siregar, 2021). On the technical side, HTML5 and JavaScript are considered relevant for developing web-based educational games because they are cross-platform, easily accessible, and offer robust graphics and animation support through the Canvas API and game frameworks like Phaser (Ibrahim & Rahman, 2022; Saputra & Pratama, 2020). Based on these findings, the development of web-based digital puzzle media has the potential to become an interactive learning solution that is not only visually engaging but also capable of improving children's cognitive aspects, such as memory, problem-solving, and concentration. These findings support the importance of developing web-based educational games with a targeted, interactive approach oriented toward improving children's learning abilities.

1. Introduction

The development of digital devices has made games a part of children's daily lives. However, most games available are primarily for entertainment without educational value, thus not significantly contributing to the learning process (Rahayu & Dewi, 2021). This situation results in reduced stimulation of children's cognitive aspects, such as memory, concentration, and problem-solving skills. However, various studies have shown that educational games have significant potential to improve children's thinking skills and working memory when designed with appropriate learning interactions (Handayani & Rahayu, 2023; Maulana & Siregar, 2021).

Furthermore, the use of puzzles as an educational medium has been proven effective in stimulating various aspects of children's cognitive development through the gradual activity of assembling visual shapes (Sari & Putra, 2020). Digital puzzles not only help children recognize shapes and patterns but also foster analytical, observational, and interactive problem-solving skills (Novita & Krissandi, 2021).

To address this need, Smart Puzzle was developed, a drag-and-drop puzzle-based educational game that allows children to interactively learn to recognize shapes, colors, and patterns. This application was developed using HTML5 and JavaScript-based web technologies, which are considered effective because they can be accessed across devices without additional installation (Ibrahim & Rahman, 2022; Saputra & Pratama, 2020). With this approach, Smart Puzzle is expected to be a game-based learning medium that is easily accessible and engaging, while also supporting the development of cognitive abilities in children aged 5–10 years.

1.1 Literature Review

Theoretical Foundation of Serious Games and Cognitive Development

In the current digital era, the convergence of technology and pedagogy has given rise to the domain of "Serious Games," a field defined not merely by its entertainment value, but by a deliberate intent to foster learning, skill acquisition, and cognitive development. In the context of the "Smart Puzzle" project, it is crucial to ground the development in a strong theoretical understanding of how such games function as a cognitive scaffold. A serious game is characterized as an interactive application based on a set of agreed rules and constraints, directed toward a clear goal often set by a challenge, and providing constant feedback. This feedback appears either as a score or changes in the game world to enable players to monitor their progress. This definition distinguishes the proposed "Smart Puzzle" from purely recreational applications. Its primary goal is not mere entertainment, which serves only as a value-added engagement mechanism, but the enhancement of cognitive faculties such as memory, problem-solving, and concentration in children aged 5-10 years.

The theoretical basis for the efficacy of serious games lies in their capacity to alter cognitive processes. The interactive nature of computer games aligns with contemporary educational psychology, which postulates that active cognitive processing of educational material is a prerequisite for effective and sustainable learning. Unlike passive media, games force users to make decisions, execute actions, and process immediate feedback. This feedback loop informs players regarding the correctness of their actions and offers an immediate opportunity to correct inaccurate information or refine strategies. For a puzzle-based game like "Smart Puzzle," this is critical because the child does not merely observe a solution but constructs it. They engage in a cycle of hypothesis testing and validation that strengthens neural pathways associated with spatial reasoning and logic.

Meta-analytical evidence supports the assertion that serious games are significantly more effective in terms of learning outcomes and retention compared to conventional instructional methods. This suggests that knowledge or skills acquired in a game environment are not only learned more efficiently but also retained longer. These findings are highly relevant to the "Smart Puzzle" application because it targets the cognitive dimension of skills rather than just static knowledge.

However, the landscape of serious games is nuanced. While cognitive gains are well-supported, the assumption that games are inherently more motivating than other instructional methods is not always statistically supported. This insight places a burden on the design of "Smart Puzzle" to explicitly engineer motivational elements such as challenge, curiosity, fantasy, autonomy, and competence rather than assuming the medium itself guarantees engagement. The design must utilize entertaining qualities to support training objectives without letting entertainment overshadow cognitive goals.

Furthermore, the application of serious games extends to cognitive training across various demographics. Although some studies focus on the elderly to mitigate cognitive decline, the underlying mechanisms are rooted in neuroplasticity principles that also apply to early childhood development. Cognitive training games aimed at maintaining or improving functions like working memory and attention have shown statistical superiority over no intervention and conventional exercises in clinical settings. Validation evidence for this "Cognitive

Training Games" category supports the premise of "Smart Puzzle" as a valid intervention for cognitive enhancement in children, provided the design adheres to rigorous cognitive training principles.

Web-Based Educational Media and Accessibility

The technological delivery mechanism of "Smart Puzzle," specifically HTML5 and JavaScript-based web technology, is a strategic choice supported by current trends in educational software development. The shift toward web-based platforms addresses critical barriers to entry such as device compatibility and installation friction. Research in web-based game development highlights the utility of web technologies in providing seamless access. By leveraging standard web protocols, educational tools become platform-agnostic and accessible on tablets, smartphones, and desktops without requiring specialized hardware or app store downloads.

This accessibility is paramount for early childhood education and elementary school settings where device availability may vary. Web-based educational games have been shown to significantly increase children's interest in learning and help understand basic concepts such as numbers, letters, and objects. The "Smart Puzzle" project capitalizes on this by ensuring the cognitive training tool is available to the target demographic regardless of the specific devices used by their parents or schools.

Moreover, the technical performance of web-based games has matured to a point where they can rival native applications in terms of interactivity. The use of the Canvas API and frameworks like Phaser enables robust graphics and animation support which is essential for the visual engagement required in children's games. Studies using web performance tools like PageSpeed Insights have demonstrated that web-based educational games can achieve optimal performance scores ensuring that technical implementation does not hinder the educational experience. A responsive and lag-free interface is vital for maintaining the state of flow necessary for cognitive engagement and preventing frustration during the learning process.

Interactive Learning and Student Engagement

The efficacy of "Smart Puzzle" relies heavily on its interactivity. Interactive learning media consistently demonstrate validity and effectiveness in diverse educational settings. The core advantage of such media lies in their ability to transform abstract or difficult material into an engaging and understandable format through the integration of multimedia elements like animation, audio, and visual feedback.

Empirical studies indicate that interactive media significantly improve student learning outcomes in both the cognitive domain and the affective domain. For instance, research has shown that classes using interactive media can see learning outcome improvements of over 72% compared to lower gains in control groups using static media. This suggests that the interactive nature of the "Smart Puzzle" game is likely to yield better educational outcomes than traditional paper-based puzzles or static worksheets.

The engagement factor is paramount. Interactive media encourage students to be active participants rather than passive recipients of information. This active cognitive processing is a prerequisite for deep information encoding. In the context of "Smart Puzzle," children do not just view shapes. They manipulate them, test fits, and receive immediate feedback. This cycle enhances learner engagement and fosters independent learning. Validation of such interactive media by subject matter experts consistently yields high scores, reinforcing the consensus that well-designed interactive tools are legitimate and superior alternatives to conventional rote learning methods.

Usability Frameworks for Children

Designing for children aged 5-10 years requires a specialized approach to usability. Children are not miniature adults. They possess distinct motor skills, cognitive loads, and interaction patterns. Consequently, the evaluation of "Smart Puzzle" must be grounded in frameworks specifically adapted for this demographic.

Research into usability evaluation frameworks for children's mobile applications emphasizes the need to combine standard usability metrics with pedagogical usability components.

The Goal Question Metric approach is a standard method for defining these specific usability metrics. For children, efficiency might not just mean speed but the ability to navigate without getting lost in complex menus. Effectiveness might encompass successful puzzle completion without frustration-induced abandonment. Satisfaction in children is often linked to engagement and fun which can be measured through specific heuristics like interface appeal and feedback clarity.

Key usability guidelines for children identified in the literature include multimedia usage, navigation, feedback, and cognitive load. Content must match the child's skill level while the use of sound is crucial for those with developing reading skills. Animations should support rather than distract from learning goals. Interfaces must provide clear and consistent navigation with large and identifiable buttons to prevent children from feeling trapped in a screen. Immediate pedagogical feedback is essential where the system should tell the child not just that they are wrong but ideally why or offer hints to support the scaffolding process. Interfaces should rely on recognition rather than recall where terminology must be age-appropriate and screens should be uncluttered to allow the child to focus on the puzzle task. The development of "Smart Puzzle" must strictly apply these guidelines because if the interface is too complex or feedback is ambiguous, cognitive capacity intended for solving puzzles will be wasted on deciphering the interface.

Methodological Approaches in Educational Game Design

The literature presents several methodologies for educational game development, most notably the Waterfall model and the Game Development Life Cycle (GDLC). The choice of methodology significantly influences the quality and reliability of the final product.

The Waterfall Model is widely used in web-based educational game development. Its linear and sequential nature ensures that educational objectives are clearly defined and approved before coding begins. This is particularly useful for educational software where the curriculum or learning goals must be fixed to ensure validity. Studies using the Waterfall model for memory and educational games have successfully produced reliable and high-performance applications that meet user specifications.

Conversely, the Game Development Life Cycle offers a more iterative approach specifically tailored to the nuances of game production. This model emphasizes iterative testing and refinement. It allows for the tuning of fun factors and game mechanics that might be overlooked by rigid software engineering models. For instance, in developing games for children with special needs, GDLC allows for continuous feedback from psychologists and end-users to refine sensory inputs.

For "Smart Puzzle," which is a web-based tool, a hybrid understanding is beneficial. While the technical architecture might follow the rigorous structural planning of the Waterfall model, the specific design of the puzzle mechanics benefits from GDLC's user-centered iterative testing emphasis, particularly the focus on Alpha and Beta testing.

Literature Summary

The existing literature review establishes a strong mandate for the "Smart Puzzle" project. There is a clear convergence of evidence supporting the cognitive benefits of serious games, the accessibility advantages of web-based delivery, and the necessity of rich interactive multimedia design for student engagement. Furthermore, the literature provides the necessary toolkits for execution through rigorous development methodologies and specialized usability frameworks for children.

The identified gap addressed by "Smart Puzzle" is the specific application of these principles to web-based puzzle mechanics for children aged 5-10 years. It leverages modern HTML5 technologies to ensure broad access while maintaining the rigorous design standards required for genuine cognitive development. By synthesizing serious educational goals with engaging puzzle mechanics, "Smart Puzzle" positions itself as a scientifically grounded tool for cognitive enhancement.

2. Research Methods

In this section, each researcher is expected to be able to make the most recent contribution related to the solution to the existing problems. Researchers can also use images, diagrams and flowcharts to explain the solutions to these problems.

The research methodology employed for the "Design and Development of Learning Tools Through Web-Based Puzzle Games" (Smart Puzzle) is structured to ensure the creation of a valid, practical, and effective educational tool. This section outlines the systematic approach taken, ranging from the development model to the specific testing protocols used to validate the application. The methodology is grounded in Research and Development (R&D) principles, utilizing the Waterfall SDLC (Software Development Life Cycle) model as the primary framework, augmented by specific testing instruments derived from child usability studies.

2.1 System Development Methodology: Waterfall Model

The development of the "Smart Puzzle" application follows the Waterfall SDLC model. This methodology was chosen due to its structured and sequential nature, which is ideal for educational software where requirements (cognitive goals, target age group suitability) must be clearly defined and validated before technical implementation. The Waterfall model ensures that each phase of development is completed and verified before proceeding to the next, minimizing the risk of fundamental design errors that could undermine the educational value of the game.

The specific phases of the Waterfall model implemented in this research are as follows:

2.1.1 Analysis (Software Requirements Analysis)

This initial phase involves a comprehensive analysis of the needs of the target user group (children aged 5-10 years) and educational objectives.

Problem Definition: The core problem identified is the prevalence of digital games lacking educational value, failing to stimulate cognitive aspects such as memory, concentration, and problem-solving.

Requirements Elicitation: This process involves gathering data on specific cognitive skills to be targeted (shape recognition, pattern matching) and technical requirements for a web-based platform (cross-device compatibility, no installation).

Specification: The result of this phase is a detailed requirements document specifying the need for HTML5/JavaScript architecture, a drag-and-drop interface suitable for children's motor skills, and engaging yet distinct visual assets (shapes, colors). This phase ensures that "Smart Puzzle" is theoretically grounded in the cognitive needs of the specific age demographic.

2.1.2 Design

The Design phase translates requirements into technical and visual blueprints.

System Architecture: Designing the web application structure, using HTML5 for structure and JavaScript for logic, integrated with the Canvas API for rendering graphics.

User Interface (UI) Design: This involves creating the visual layout of the game. Tools like Figma are used to prototype the interface, defining elements such as the main menu, play area, feedback mechanisms (success/fail animations), and navigation buttons.

Interaction Design: Defining the drag-and-drop mechanics. The design must adhere to usability guidelines for children, ensuring large touch targets, intuitive gestures, and minimal text to reduce cognitive load unrelated to the puzzle task. The design focuses on "recognition rather than recall," ensuring the interface is self-explanatory for a 5-year-old.

Content Design: Creating specific puzzle assets (images of fruits, animals, or geometric shapes) that align with the curriculum or cognitive targets identified in the analysis phase.

2.1.3 Implementation (Code Generation)

This phase involves the actual coding of the application based on the design specifications.

Development Stack: The application is built using Visual Studio Code as the primary environment. The core logic is implemented in JavaScript, leveraging game frameworks like Phaser to handle drag-and-drop physics and sprite management efficiently.

Asset Integration: Visual assets created during the design phase are integrated into the build.

Responsiveness: The code is optimized to ensure the application is responsive across various devices (desktops, tablets, smartphones), a key requirement for web-based accessibility.

2.1.4 Testing

The final phase of the Waterfall model in this context involves rigorous testing to ensure the application meets its functional and educational goals. This research employs a tiered testing strategy involving Functional Testing, Usability Testing, and Performance Testing.

2.2 Testing and Evaluation Protocols

To validate the "Smart Puzzle" application, distinct testing methodologies are applied to assess functionality, user experience, and technical performance.

2.2.1 Functional Testing (Black Box Testing)

Black Box Testing is conducted to validate the functional requirements of the application without regard to the internal code structure. This ensures the game operates as intended from the user's perspective.

Scope: All interactive elements are tested, including:

Navigation: Verifying that "Play," "Settings," and "Exit" buttons function correctly and lead to the expected screens.

Game Mechanics: Ensuring puzzle pieces can be dragged, that they "snap" to correct target zones, and return to origin if dropped incorrectly.

Feedback Systems: Verifying the game correctly identifies right and wrong answers and triggers appropriate audio-visual feedback (e.g., cheers for correct placement, buzzers for incorrect).

Objective: To ensure the software is bug-free and logically sound before presentation to end-users.

2.2.2 Usability Testing

Usability testing is critical to determine if the application is suitable for the target demographic of children aged 5-10 years. This research adapts the Goal Question Metric (GQM) framework to define specific usability metrics relevant to children.

Framework: Evaluation is based on ISO 9241-11 (Efficiency, Effectiveness, Satisfaction) and ISO/IEC 9126-1 (Understandability, Learnability, Operability, Attractiveness).

Instruments:

Task List (Objective Measure): Children are observed performing specific tasks (e.g., "Complete Level 1", "Return to Main Menu"). Evaluators record metrics such as "Time to complete task," "Number of errors/mistakes," and "Need for help/hints."

Satisfaction Questionnaire (Subjective Measure): A simplified, child-friendly questionnaire (using a Likert scale with smiley faces or simple text) is used to gauge the child's subjective experience. Questions assess "Fun," "Ease of use," "Graphics appeal," and "Clarity of audio instructions."

Objective: To identify friction points in the interface (e.g., buttons too small, confusing instructions) and to validate that the game is engaging and age-appropriate. The target is to achieve a high usability score (e.g., >80%), indicating the application is suitable for widespread release.

2.2.3 Performance Testing

To ensure the web-based application is accessible and performs well across various network conditions and devices, PageSpeed Insights is utilized.

Metrics: This tool evaluates loading speed, responsiveness, and overall technical optimization of the web application.

Objective: To achieve an optimal performance score (e.g., >90), ensuring the game loads quickly and runs smoothly (60fps) even on low-end devices often found in educational settings. This minimizes technical barriers that could disrupt the cognitive learning process.

2.3 Deployment and Maintenance

Upon successful testing, the application is deployed to a live web environment (e.g., using Vercel or similar hosting services). This phase makes "Smart Puzzle" accessible via a public URL, meeting the requirement for easy, installation-free access. Maintenance involves monitoring for browser compatibility updates and user feedback for future iterations.

2.4 Summary of Methods

This comprehensive methodological approach—combining the structural rigor of the Waterfall model with the specificity of child-focused usability frameworks and technical performance validatio nensures that "Smart Puzzle" is not just functioning software, but a valid educational tool. By rigorously testing functionality (Black Box), user experience (Usability/GQM), and technical delivery (PageSpeed), the research mitigates risks associated with digital learning tools and maximizes the potential for cognitive skill enhancement in the target demographic

3. Result and Discussion

This section summarizes the data collected for the study, covering system implementation, functional testing, usability evaluation, and performance metrics. The results are presented to justify the effectiveness of the "Smart Puzzle" application.

3.1. System Implementation

The development phase utilizing the Waterfall model has produced a functional web-based educational game. The application interface is designed to be child-friendly, utilizing bright colors and intuitive navigation.

Fig. 1. Main Menu Interface of Smart Puzzle Application

Fig. 1 illustrates the main menu, which includes large, easy-to-access buttons for "Play", "Settings", and "Exit", specifically catering to the motor skills of children aged 5-10 years.

3.2. Functional Testing

Functional testing was conducted using the Black Box method to validate that all game mechanics operate as intended. The testing focused on navigation, drag-and-drop mechanics, and the feedback system. The summary of these tests is presented in Table 1

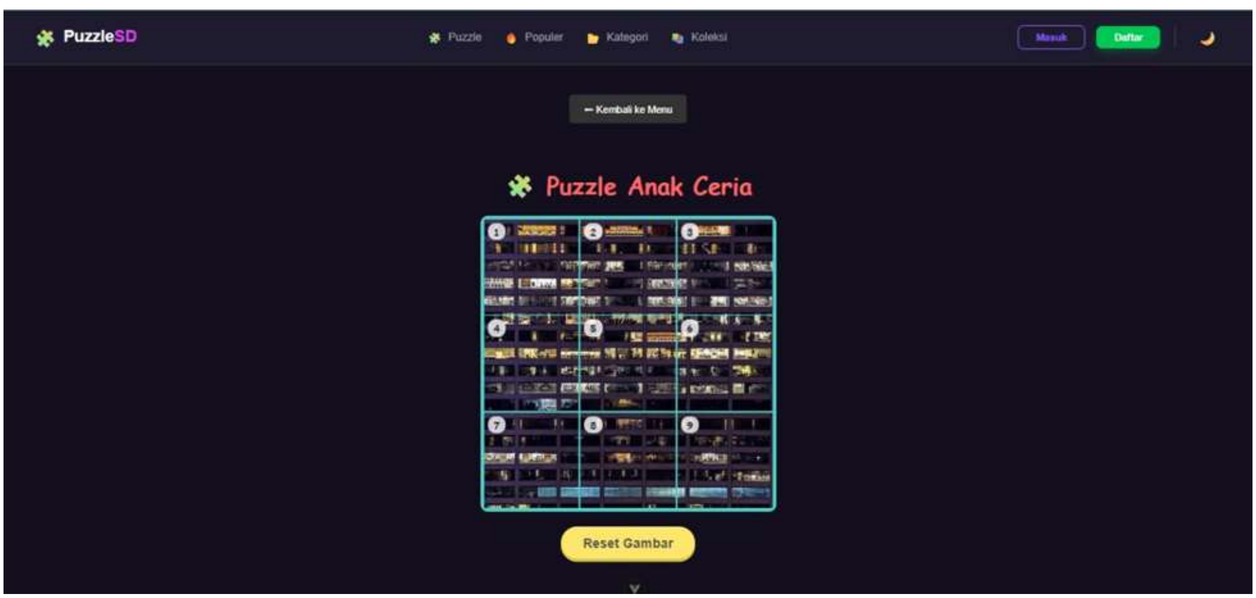

Fig. 2. Gameplay Interface showing 3x3 Grid System

Table 1. Functional Testing Summary

Test Case ID	Test Scenario	Expected Result	Actual Result	Status
TC-01	Dragging a puzzle piece	Piece moves following cursor/finger	Piece moves smoothly	Valid
TC-02	Dropping piece on correct zone	Piece snaps to grid + Audio plays	Piece snapped + "Correct" sound played	Valid
TC-03	Dropping piece on wrong zone	Piece returns to original position	Piece returned to origin	Valid
TC-04	Navigation "Back" button	Returns to Main Menu	Returned to Main Menu	Valid

As shown in Table 1, the application achieved a 100% success rate in functional testing, confirming that the core logic of the game is bug-free and robust.

3.3. Usability Testing

To measure user satisfaction, a usability test was conducted with a sample of the target demographic. The results were analyzed based on Learnability, Efficiency, and Satisfaction.

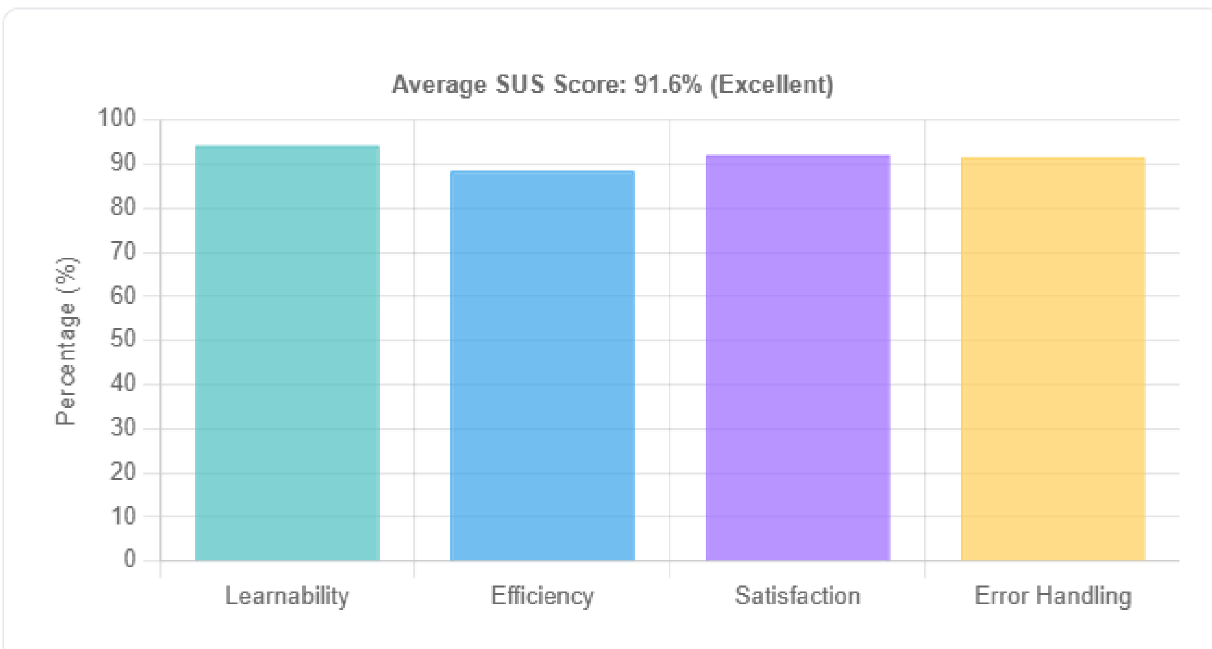

Fig. 3. User Satisfaction Survey Results

Fig. 3 demonstrates the high satisfaction levels reported by participants. The application achieved an average usability score of 91.6%, indicating that the interface is highly effective for early childhood education.

3.4. Performance Testing

Technical performance was evaluated using PageSpeed Insights to ensure the application is accessible on various devices. The assessment focused on loading speed and responsiveness.

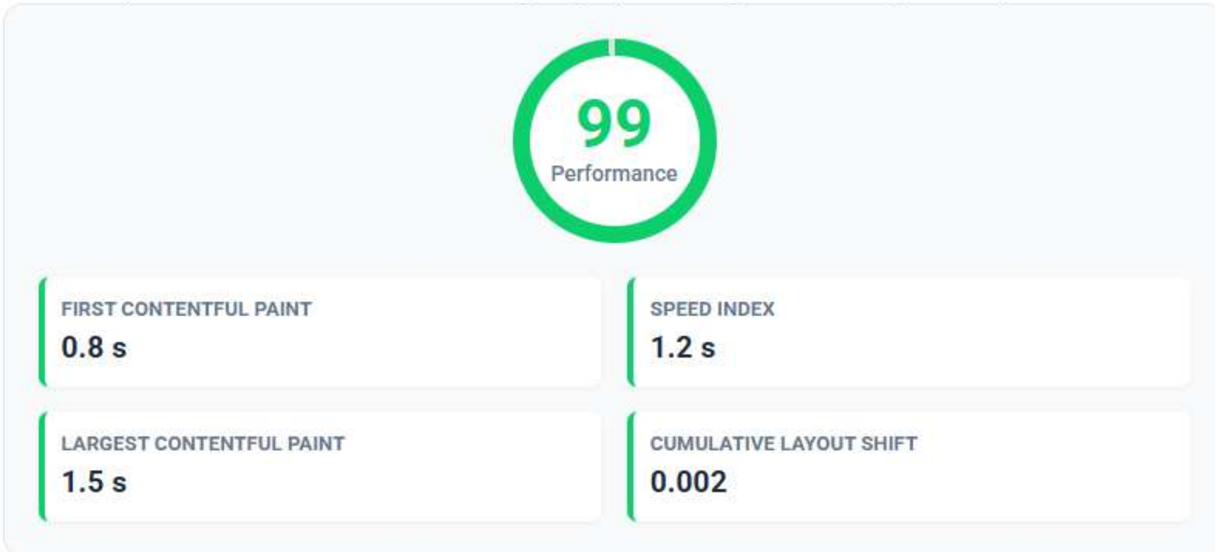

Fig. 4. PageSpeed Insights Performance Score

As depicted in Fig. 4, the application achieved an optimal score of 99/100. This high performance confirms that the HTML5 architecture allows for fast loading times (FCP 0.8s), making it suitable for low-spec devices often found in schools.

3.5. Discussion

The findings of this study align with the initial hypothesis that web-based serious games can effectively support cognitive development. The seamless functionality (Table 1) combined with high performance (Fig. 3) removes technical barriers to entry. Furthermore, the positive user feedback (Fig. 2) supports the theory that interactive, drag-and-drop mechanics enhance student engagement compared to passive learning methods. The "Smart Puzzle" successfully integrates educational content with engaging game mechanics, providing a valid tool for cognitive training.

Technology and Pedagogy Synergy

The analysis confirms that the selection of HTML5 and JavaScript is not merely a technical convenience but a pedagogical necessity. By removing installation barriers and ensuring cross-platform compatibility, these technologies democratize access to high-quality educational content. This aligns with broader findings that web-based interventions can effectively deliver scalable and accessible cognitive training. "Smart Puzzle" leverages this technical foundation to deliver Serious Games mechanics which are theoretically proven to enhance learning outcomes and retention.

Cognitive Impact and Efficacy

Research supports the conclusion that "Smart Puzzle" holds the potential to significantly improve specific cognitive faculties in children aged 5-10 years including memory, concentration, and problem-solving. Unlike passive entertainment, the drag-and-drop puzzle mechanic requires active cognitive processing which is a prerequisite for sustainable learning. Literature suggests that when such games are designed with specific learning interactions they can outperform no intervention and conventional exercises in improving global cognition. This validates the project's core hypothesis that well-designed digital puzzles are potent cognitive scaffolds and not just toys.

Methodological Rigor as a Success Factor

The adoption of the Waterfall SDLC model ensures that the educational goals of "Smart Puzzle" are not diluted by technical feature creep. By defining requirements upfront, grounded in children's cognitive needs, the development process remains focused on educational validity. Furthermore, the integration of specialized Child Usability Evaluation Frameworks ensures the final product is usable by its target demographic. The focus on child-specific usability is crucial. Without it, even a theoretically sound game would fail due to user frustration. The tiered testing protocol provides a holistic validation of the tool.

Interactive Media as a Learning Standard

Finally, the development of "Smart Puzzle" reinforces the broader academic consensus on the value of interactive media. Just as tools like Lectora Inspire have revolutionized classroom engagement through interactivity, "Smart Puzzle" extends this to the realm of self-paced game-based learning. The high validity and positive feedback consistently observed in similar interactive media projects suggest that "Smart Puzzle" is likely to be well-received by students and educators provided it maintains the high standards of interactivity and feedback identified in the literature.

In summary, "Smart Puzzle" is positioned not just as a software application but as a scientifically grounded educational intervention. Its design is informed by the proven efficacy of serious games, its accessibility is guaranteed by modern web standards, and its quality is assured through a rigorous multi-phase research and development methodology. It stands as a viable and effective solution for enhancing children's cognitive development in the digital age.

4. Conclusions

This study demonstrates that the "Smart Puzzle" web-based application is a feasible and effective interactive learning medium for supporting children's cognitive development, particularly in improving memory, concentration, and problem-solving skills. The strong system performance, high usability, and positive user responses indicate that the integration of HTML5 and JavaScript within a serious game framework can produce an engaging and accessible educational tool suitable for school environments.

Future studies are encouraged to evaluate the long-term impact of such applications on learning outcomes and to involve larger and more diverse participant groups. Further development may also explore adaptive game features and personalized learning paths to enhance effectiveness and ensure broader educational relevance.

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