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Development and usability evaluation of an educational game for learning data structure concepts involving sorting, queue, and stack

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ABSTRACT

Learning data structure concepts at the Junior High School (SMP) level is often hampered by conventional delivery methods. Minimal visual representation sometimes makes it difficult for students to imagine how data is structured and processed, which impacts their lack of understanding and computational thinking skills. This study aims to develop and evaluate an HTML5-based educational game called "DATA WORLD" designed to help 8th-grade junior high school students understand the concepts of Array, Stack, and Queue data structures. This study uses the Research and Development (R&D) method with the ADDIE model consisting of five stages: Analysis, Design, Development, Implementation, and Evaluation. The game was developed using Construct 3 software and its effectiveness was evaluated on 32 8th-grade junior high school students using the System Usability Scale (SUS) instrument. The development results show that this game functionally succeeds in visualizing how data structures work concretely through document sorting challenges for sorting, First-In-First-Out (FIFO) customer queue simulations for queues, and Last-In-First-Out (LIFO) block stacking activities for stacks. Usability testing yielded an average SUS score of 82.5%, indicating excellent user acceptance. In conclusion, this educational game has proven functionally and pedagogically feasible as a companion learning tool for data structures. The interactive approach effectively bridges gaps in student understanding through a visual learning experience that is self-paced, enjoyable, and aligned with the learning outcomes of the informatics curriculum. Eighty-one percent of participants had never played a similar educational game before, ensuring authentic and unbiased assessments.

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INTRODUCTION

Education in the digital era requires the integration of information technology to improve learning effectiveness, especially for abstract informatics subjects (Shute et al., 2021). Textbook-based learning with teacher centered lectures makes students passive, reducing motivation and knowledge retention (Arifah et al., 2019). A review of 113 articles (2017–2021) found that game-based methods in computer science education consistently increase student engagement and knowledge retention. However, most implementations focus on computational thinking and programming skills, leaving a gap in topics like data structures which this study addresses (Videnovik et al., 2023). Data structures are fundamental concepts for organizing and managing data efficiently (Rueden et al., 2023). Poor understanding of these concepts hinders optimal algorithm design. Undergraduate students face similar challenges due to the abstract nature of the material, low motivation, and lack of engaging tools (Srihith et al., 2023). A pilot study with 51 university students showed that teaching data structures and algorithms (DSA) using a game with 2.5D visual animations (the DeCode game) made learning more enjoyable and effective, helping students solve classic problems like array shifting (Su et al., 2021). This confirms that visual and game-based teaching strategies are applicable across educational levels. Therefore, mastering data structures from an early age is essential for preparing young people for the information technology field.

The data structure material studied at the junior high school level includes several basic types that have different characteristics and working mechanisms. The first type is an *array*, a data structure that stores elements of the same data type in a linear order and adjacent memory positions, allowing random access based on specific indices. The second type is a *stack*, which applies the Last In First Out (LIFO) principle, where the last element entered into the stack will be the first element removed. The third type is a *queue*, which works on the opposite principle, First In First Out (FIFO), so that the first element entered will be the first element to exit. Mastering these three types of data structures is the main foundation for building programming logic and systematic computational thinking skills (Almansoury et al., 2022; Zhao et al., 2022).

Although they have a vital role in computing, the delivery of data structure material in schools today is often constrained by various technical limitations in the learning media used. The dominant teaching methods are still conventional, centered on lectures, note-taking of definitions, and working on theoretical questions with minimal hands-on practice. This aligns with findings that text-based approaches alone are insufficient to provide concrete visualization of how complex algorithms and data storage work for students (Bang et al., 2023; Hanifurohman et al., 2025). As a result, students only memorize definitions without truly understanding how arrays, stacks, and queues work in real scenarios. Beyond comprehension deficits, the absence of engaging and interactive learning media also affects students' intrinsic motivation a factor that is foundational to sustained learning. A large-scale empirical study conducted across three universities in Thailand involving 434 students found that digital educational games exert a statistically significant positive influence on students' motivation for learning, with learning engagement functioning as a key mediator in this relationship. Furthermore, the study demonstrated that the positive impact of digital games on engagement is amplified when students are situated within a more immersive digital environment, underscoring the importance of designing learning games that not only convey content accurately but also cultivate an emotionally stimulating and contextually rich experience (Li et al., 2024). They have difficulty imagining how data is arranged, stored, and processed in computer memory because there is no visual representation they can observe directly.

Several existing educational games, such as *Lightbot*, *Algorithm City*, and *Coding Adventure*, have been used to introduce basic programming logic. In a broader effort to address the same disengagement challenge in STEM education, Zhao et al. (2022) conducted a large scale study on serious games in university programming courses and found that game-based learning consistently improved knowledge acquisition, learner experience, and usability, though the impact

varied by location, background, and game type. These games visualize abstract concepts through meaningful scenarios, a design approach that informs this study. However, they generally focus on sequencing, loops, and conditionals rather than on visualizing memory behavior during data structure operations. The proposed game, "DATA WORLD", has several unique contributions: (1) visualizing changes in index and memory capacity in real-time, (2) providing immediate error-specific feedback when students violate stack or queue rules, and (3) enabling direct comparison of stack and queue behavior using identical datasets. These features distinguish "DATA WORLD" from other educational games such as Lightbot, Algorithm City, or Coding Adventure, which generally lack proper LIFO/FIFO simulations and conceptual error feedback tailored to learning data structures. Direct observation at junior high schools confirmed that many eighth-grade students struggled to visualize these mechanisms because existing media lack interactive, precise simulations (Rodriguez-calzada et al., 2024).

The structural design of DATA WORLD also takes into account findings regarding gameplay modes and their differential effects on learning outcomes. Research by Zou et al. (2021) involving 90 university students who engaged with a digital role-playing game across collaborative, competitive, and solo modes revealed that solo gameplay consistently produced inferior outcomes across all measured dimensions including learning performance, motivation, self-efficacy, and flow experience compared to collaborative and competitive modes. While DATA WORLD is currently designed for individual use, these findings highlight the pedagogical value of incorporating social interaction mechanisms in future iterations of the game to further amplify its impact on student engagement and knowledge retention.

The problem lies in the fact that existing digital learning tools do not provide visually accurate LIFO/FIFO simulations (Almansoury et al., 2022), as stacks are often displayed as ordinary lists without access restrictions. When a student incorrectly removes an element from the wrong end of a queue, the system does not explain why the operation is invalid (Irham, 2020). Another critical weakness is the absence of comparative visualization, meaning students cannot simultaneously observe how the same sequence of insertions and deletions behaves differently in a stack versus a queue. Without these technical features, students' retention of data structure concepts remains low, and they struggle to connect theoretical definitions to practical application. The problem of weak feedback mechanisms in existing tools connects to a broader pedagogical concern regarding the role of in-game support systems in facilitating genuine conceptual understanding. Shute et al. (2021) conducted a randomized experimental study involving 263 high school students using the Physics Playground game, revealing that physics animations constituted the most effective in-game support among eight tested modalities, significantly predicting both learning outcomes and in-game performance. Thus, the research gap addressed in this study is the absence of interactive visual media that not only explains data structure concepts but also provides real-time rule-based feedback and comparative LIFO/FIFO visualizations in a single integrated platform, while most existing educational games focus only on basic programming logic or offer static representations of data structures without simultaneously supporting array sorting, FIFO queue simulation, and LIFO stack simulation with instant error detection and side-by-side comparison of these mechanisms. This finding substantiates the design rationale behind DATA WORLD's real-time visual feedback system, which uses animated representations of LIFO and FIFO operations to make abstract memory manipulation behaviors cognitively accessible and observable during gameplay.

Based on the technical gaps described above, this study formulates the following research question: how can an Android-based educational game called "DATA WORLD" be designed and developed to visualize array, stack, and queue operations with LIFO/FIFO accuracy while providing instant feedback on user errors? To answer this question, the research objectives are fourfold: first, to implement real-time visualization of index changes and capacity limits during array, stack, and queue operations; second, to provide an instant error-detection system that

notifies students when they violate LIFO (stack) or FIFO (queue) rules; third, to develop the game using the ADDIE model and the Construct 3 engine, making it accessible on Android devices commonly used by junior high school students; and fourth, to evaluate the effectiveness of "DATA WORLD" in improving students' understanding compared to conventional text-based or lecture-only methods. The urgency of this research lies in the scarcity of academically valid, technically precise, and practically usable learning media for data structure visualization in junior high school environments (Mashuri et al., 2024).

RESEARCH METHODOLOGY

This study employs a Research and Development (R&D) approach aimed at producing an HTML5-based educational game product while simultaneously testing its feasibility as a learning medium for data structure concepts for eighth-grade junior high school students (Su et al., 2021). The development model used is ADDIE (Hasanah et al., 2025), which consists of five systematic stages: Analysis, Design, Development, Implementation, and Evaluation. The ADDIE model was chosen because its structured and flexible step-by-step framework facilitates researchers in designing, developing, and evaluating technology-based learning products comprehensively (Made et al., 2025).

This choice is further reinforced by evidence from project-based learning research in engineering education. Gomez-del & Rodríguez (2022), demonstrated that structured, hands-on learning frameworks particularly those integrating innovative technologies within a systematically organized pedagogical sequence were effective in helping students integrate disciplinary knowledge and improve design-related competencies across both mechanical and chemical engineering programs. Although the subject matter differs, the underlying pedagogical principle is transferable: when students interact with structured learning experiences that progressively build in complexity and provide concrete activities, their conceptual understanding deepens in ways that conventional lecture-based methods cannot replicate.

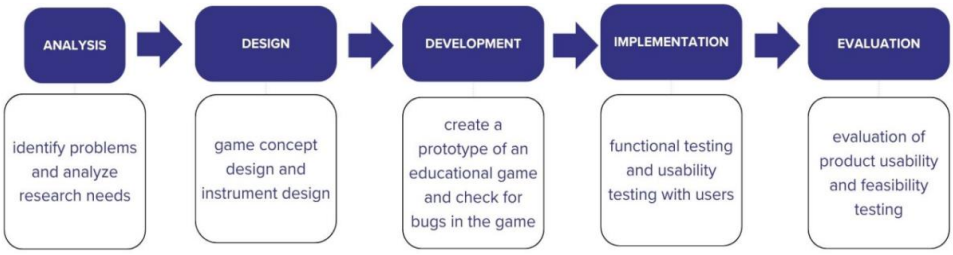

Figure 1. DATA WORLD game development stages

In the analysis phase, this study identified learning problems and needs at the junior high school level through observations and interviews with ICT teachers, with a primary focus on addressing students' difficulties in understanding abstract concepts such as arrays, stacks, and queues. Next, the game flow was designed using flowcharts and storyboards, including the main menu, game instructions, theoretical materials, and interactive challenges based on data structure concepts. The development phase realized an educational game prototype using the Construct 3 game engine, where the game's functionality was internally tested to fix bugs. In the implementation phase, the educational game was implemented in ICT learning sessions for 8th-grade junior high school students to encourage direct interaction and student engagement. The adopted implementation strategy aligns with best practices from game-based adaptive research at the elementary level, as shown by (Bang et al., 2023) that students using the My Math Academy adaptive game experienced more significant improvements in learning outcomes than the control group, especially for students with low initial competencies. This supports the potential of DATA

WORLD remediation for 8th-grade students who have limited initial exposure to data structure concepts, allowing game media to act as an equalizing tool in heterogeneous classes. Finally, the evaluation stage assesses the effectiveness of the media through formative evaluation (feedback during the process) and summative evaluation (understanding tests and motivation questionnaires) to measure the impact of the product on learning outcomes.

Participants

In this study, 32 junior high school students participated with the following composition: 15 male students (47%) and 17 female students (53%). Regarding their experience with similar applications, 26 students (81%) had never played an educational game like this before, while only 6 students (19%) had previous experience. This data indicates that the majority of participants were beginners in interactive game-based learning media. Below is a table showing the list of participants.

Table 1. Participant information

Information		N	%
Gender	Male	15	47
	Female	17	53
Total		32	100
Have you ever used a similar app?	Ever	6	19
	Never	26	81
Total		32	100

The selection of 32 students was based on usability testing standards, which recommend that 15–20 participants be sufficient to identify most usability issues (Swacha et al., 2025). This number also meets the Central Limit Theorem, which states that samples of size n ≥ 30 tend to produce a normal distribution (Okoro, I., Uka, C. O., & Ogbara, 2023). This study employed total sampling involving all available 8th-grade students (N=32) to avoid selection bias and enhance internal validity.

Instruments and Data Analysis

Usability measurement used the System Usability Scale (SUS), a reliable instrument for assessing the ease of use of applications and digital media by end users. The SUS questionnaire consists of 10 questions using a 5-point Likert scale. SUS score calculation was performed by converting each response to a numerical value, where responses to odd-numbered statements were calculated using the formula response value minus 1, while responses to even-numbered statements were calculated using the formula 5 minus the response value. The results from all statements were then summed and multiplied by 2.5 to produce a final score ranging from 0 to 100.

Table 2. SUS question instrument (Kesuma, 2021)

No	Question
1	I'm thinking of using the "DATA WORLD" educational game app again.
2	I found the "DATA WORLD" educational game app complicated to use.
3	I found the "DATA WORLD" educational game app easy to use.
4	I need help from others using the "DATA WORLD" educational game app.
5	I feel the features of the "DATA WORLD" educational game app work as they should.
6	I feel there are many inconsistencies (not coherent in the "DATA WORLD" educational game).
7	I feel other people will quickly understand how to use the "DATA WORLD" educational game app system.
8	I find the "DATA WORLD" educational game app confusing.
9	I don't feel there are any obstacles in using the "DATA WORLD" educational game app.
10	I need to get used to it first before using the "DATA WORLD" educational game app.

RESULTS AND DISCUSSION

The DATA WORLD game was developed using Construct 3, which supports HTML5-based game development with a visual approach, allowing the game flow to be adjusted to Computational Thinking learning objectives. This approach aligns with previous research stating that Construct 3 is effectively used in developing interactive educational games due to its flexibility and ease of implementation (Nabilah et al., 2024; Zou et al., 2021). The main features of the product include: (a) a main menu containing game explanations, start game, and exit; (b) a home menu providing access to profile, settings, and categories; (c) three categories of games: queue, array, and stack; (d) three game levels with increasing difficulty at each level; and (e) a scoring system that assesses player success in completing missions.

a. Array Data Structure

Figure 2. Array game display

In Figure 2, players are presented with four documents with random dates located on the left side of the screen. On the right side, there's a blank space to rearrange the documents in order. Players must drag each document from the left area to its correct position on the right. The goal is to sort the documents from oldest to newest, thus learning the concept of arrays through the activity of sorting data.

b. Queue Data Structure

Figure 3. Queue game display

In Figure 3, this game teaches the concept of queue data structures using the FIFO (First In, First Out) principle, where the first object to enter is the first to exit. On the left side of the screen is a shop, while on the right side is a group of people waiting in line. The player's task is to get the people waiting in line into the shop by following the correct queue order, with the person at the front (first in line) being the first to be served and enter the shop. Through this mechanism, players learn firsthand how queues in the queue data structure work in everyday life.

c. Stack Data Structure

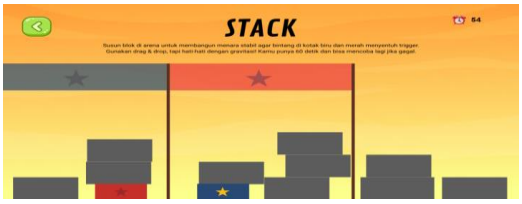

Figure 4. Stack game display

In Figure 4, this game is designed to teach the concept of stack data structures using the LIFO (Last In, First Out) principle, where the last element inserted is at the top. In the game, there are two columns with a blue flag at the top of the left column and a red flag at the top of the right column, as well as scattered boxes consisting of a gray box, one blue box, and one red box. The player's task is to stack the gray boxes first in each column, then place the blue box in the left column and the red box in the right column at the top until it touches the flag of the same color. Through this mechanism, the player learns that in a stack, access can only be done to the top element, so the colored box must be the last element added to reach the top.

Based on data collected from 32 respondents (eighth-grade students) through the System Usability Scale (SUS) instrument, the calculated average SUS score was 82,5 (after linear transformation and multiplication by 2.5). According to the interpretation criteria proposed by Bangor, Kortum, and Miller (2009), a SUS score of 82,5 falls into the "Acceptable" category with an adjective rating of "Good". This indicates that the "DATA WORLD" educational game is considered usable, easy to navigate, and well-received by junior high school students as a learning medium for data structure visualization.

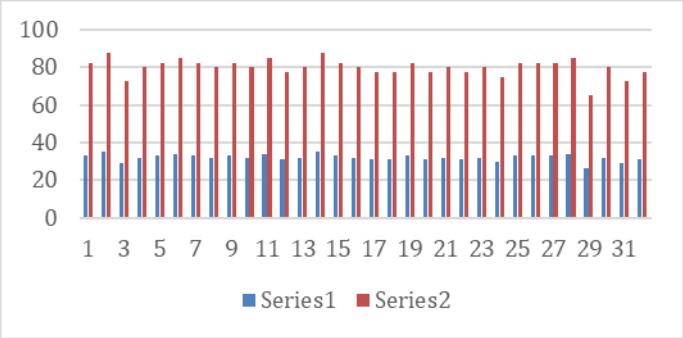

Figure 5. Results of SUS user test calculations

Furthermore, when compared to the SUS benchmark for educational software, a score of 82.5 is significantly above the average range (68–72) and even exceeds the 80th percentile, suggesting that the game's usability is superior to most similar learning applications. This finding aligns with previous research by (Li et al., 2024), who reported that game-based learning media developed with Construct 2/3 tend to achieve SUS scores in the 75–85 range due to their intuitive drag-and-drop interface and responsive touch controls on Android devices. This pattern of positive usability outcomes across game-based learning platforms is further corroborated by Zhao et al. (2022), whose comprehensive study found that all student participants benefited from the integration of serious games into programming courses regardless of their demographic backgrounds though the degree of benefit varied across subgroups. The consistency of this finding across different educational contexts and learner profiles suggests that well-designed educational games possess a broadly accessible quality that transcends individual differences, lending further credibility to the usability outcomes reported for DATA WORLD in the present study. The higher score obtained in this study (82.5) reinforces the advantage of incorporating real-time visual feedback for LIFO and FIFO operations, a feature that many existing educational games lack.

Discussion

The final product of this research is an HTML5-based educational game titled "DATA WORLD" developed using the Construct 3 platform. Technically, this game presents an interactive interface with elements such as a main menu, game instructions, material summaries, and challenge levels that test students' computational thinking abilities (Aziz et al., 2021). Each level is designed to represent the working mechanisms of data structures through visual simulations and logic puzzles. It should come as no surprise that educators are becoming more interested in the

potential of computer games as learning tools given their enormous popularity and capacity to maintain prolonged engagement with difficult tasks (Olanrewaju et al., 2018).

In terms of content feasibility, the variation in students' understanding levels shows that alternative learning media are urgently needed. The effectiveness of "DATA WORLD" in visualizing LIFO and FIFO mechanisms supports the findings of (Bang et al., 2023), who argued that text-based approaches alone are insufficient for teaching abstract algorithm concepts. Specifically, the drag-and-drop interaction implemented in this game reduces cognitive load for junior high school students, a claim consistent with studies showing that interactive simulations with instant feedback significantly improve retention rates compared to passive lecture methods. The "Excellent" SUS rating achieved in this study provides quantitative evidence that when students find a learning medium easy to use, their engagement and conceptual understanding also improve. As according to Battistella et al., (2017), when teaching sequencing algorithms, educational games can help students reach higher learning levels and boost their desires. Students can cooperate or compete while playing thanks to the social interactions that games foster, which makes learning more fun. The crucial significance that quick feedback and simple controls play in sustaining user interest and promoting efficient learning (Sukirman et al., 2024). The real-time feedback feature contributes to the understanding of LIFO and FIFO concepts by immediately blocking invalid actions (e.g., removing a non-top element from a stack or serving a non-front customer from a queue) and displaying error-specific visual notifications, which creates a cause-and-effect learning loop that reinforces correct mental models through active experimentation and instant correction.

From a design feasibility perspective, the research instrument is reliable for measuring understanding after systematic transformation, indicating conceptual validity. This supports the methodological recommendations of (Videnovik et al., 2023), who stated that the ADDIE model combined with SUS testing produces valid and replicable outcomes for educational game research. The high SUS score of 82.5 suggests that "DATA WORLD"—which visualizes real-time changes in array indices, stack tops, and queue fronts—successfully addresses gaps in existing media, namely the lack of precise LIFO/FIFO visualization and instant error feedback. This is theoretically grounded in the work of Li et al. (2024) who found through structural equation modeling that digital educational games systematically enhance learning motivation by deepening engagement, especially in immersive digital environments. Since DATA WORLD runs on the HTML5 platform that students use daily, this digital familiarity naturally facilitates engagement, making it a strategic choice for teaching data structures to learners embedded in mobile ecosystems. Game-based learning with guided questions helps students implement array and stack operations. Students can use this game for self-evaluation, and teachers can use it to diversify their teaching methods (Ramle et al., 2019).

CONCLUSION

This study successfully developed an HTML5-based educational game named "DATA WORLD" using the Construct 3 engine and the ADDIE development model. The game was designed to visualize three fundamental data structure concepts: arrays through document sorting activities, queues through FIFO (First In First Out) simulations, and stacks through LIFO (Last In First Out) block stacking challenges. Based on usability testing involving 32 eighth-grade students using the System Usability Scale (SUS), the game achieved a score of 82.5, which falls into the "Excellent" category according to the Bangor, Kortum, and Miller interpretation criteria. This score significantly exceeds the average SUS benchmark of 68–72 for educational software, indicating that the game is highly usable, easy to navigate, and well-received by students. The finding is particularly noteworthy because 81% of participants had no prior experience with similar educational games, making their positive assessments authentic and unbiased. The game successfully addresses the technical gaps identified in existing learning media by providing real-

time visual feedback for LIFO and FIFO operations, instant error detection when students violate access rules, and comparative visualization of stack and queue behaviors. In conclusion, "DATA WORLD" is pedagogically valid and functionally feasible as a supporting learning medium for data structure concepts at the junior high school level. Future development should explore adding other data structure materials, adapting the game for higher education levels, and incorporating collaborative or competitive gameplay modes to further enhance student engagement and learning outcomes. To rigorously test the impact on learning outcomes and computational thinking skills, future research should employ quasi-experimental designs with pre-test and post-test assessments comparing "DATA WORLD" users against control groups receiving conventional instruction. For teachers, this game offers practical implications as a supplemental tool for differentiated instruction, enabling students to independently visualize abstract data structure concepts before engaging in coding activities, while teachers shift from lecturing to facilitating problem-solving discussions during gameplay.

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