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Evaluating the Usability and Effectiveness of an Educational Game Integrating Human-Centric Design for Learning Basic Algorithms

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Abstract

Mastering basic algorithmic logic is a fundamental requirement in vocational informatics education; however, traditional static instructional methods often fail to engage students due to the abstract nature of the concepts. This study aims to evaluate the usability and effectiveness of an educational game, developed using a Human-Centric Design (HCD) approach and the ADDIE framework, to facilitate the learning of basic algorithms. The research involved 30 Grade X Multimedia vocational students, evaluated through a pre-test and post-test control group design. Pedagogical effectiveness was measured using Normalized Gain (N-Gain) and an Independent Sample T-test, while user acceptance was quantified using the System Usability Scale (SUS). The results demonstrated that the game-based intervention was significantly more effective than traditional lectures, achieving an N-Gain score of 63.86% (Moderately Effective) compared to the control group's 18.52% (Ineffective), with a statistical significance of p = 0.000. Furthermore, the usability evaluation yielded an average SUS score of 64.4. While this score confirms the system's functional viability and high user independence, it also identifies a steep initial learning curve, highlighting the need for a progressive onboarding phase. In conclusion, integrating HCD within educational games successfully transforms abstract programming syntax into an accessible interactive experience, effectively bridging the pedagogical gap and enhancing students' algorithmic comprehension in vocational education.

1 Introduction

Algorithms serve as the fundamental cornerstone of computer science education, representing a logical and systematic sequence of instructions designed to resolve complex problems efficiently (Türker & Pala, 2020). Within the context of Vocational High Schools (SMK), mastering basic algorithmic logic is a mandatory core competency for students specializing in Software Engineering, Multimedia, and Computer Network Engineering (Rahmawati et al., 2025). However, the pedagogical delivery of these concepts often encounters significant hurdles due to the abstract nature of the material, which necessitates high cognitive engagement from students to grasp systematic decision-making processes. Recent studies emphasize that a failure to establish a robust understanding of foundational logic at this early stage often leads to persistent difficulties in mastering more advanced programming languages and computational thinking skills (Iman, 2025). Consequently, there is an urgent need for instructional media that transcends static text to provide dynamic visualizations of systematic logical flows.

Despite the critical importance of algorithmic proficiency, contemporary classroom realities often reveal a substantial gap between traditional teaching methodologies and student engagement levels (Mahdiyah et al., 2025). Preliminary observations at a vocational school indicate that students frequently exhibit passivity and a lack of interest, primarily because the instructional tools employed are limited to conventional videos and static PowerPoint presentations (Khatter et al., 2024). These one-way instructional methods often fail to stimulate active participation, resulting in a monotonous learning environment that stifles curiosity. Educators are thus challenged to innovate by leveraging technology to align instructional delivery with the characteristics of digital-native students who favor interactive visual stimuli. Without a shift toward more engaging and interactive media, the potential for students to develop essential problem-solving capabilities remains largely untapped. This pedagogical imperative underscores the necessity for innovative educational tools that can effectively bridge this gap, enhancing both algorithmic thinking and cognitive interest (Stoika & Temetev, 2026).

As educational technology evolves, the paradigm of instructional media has shifted from traditional print-based materials toward portable, interactive digital platforms. Game-based learning has emerged as a potent solution, specifically engineered to stimulate cognitive functions, enhance concentration, and foster systematic problem-solving through immersive simulations (Singh, 2025). Integrating educational games into the curriculum has been proven to significantly bolster student motivation by creating a dynamic, learner-centered environment that encourages direct involvement in the learning process. In this regard, utilizing robust game engines like Construct 2 allows for the development of sophisticated 2D interactive simulations that are both lightweight and capable of effectively visualizing complex algorithmic structures. This approach not only simplifies complex programming concepts like inheritance and nested loops but also promotes active learning through engaging visual interfaces (Videnovik et al., 2023).

However, the development of educational games frequently prioritizes entertainment value over rigorous usability standards, often neglecting the end-user's interactive experience. A Human-Centric Design approach is essential to ensure that instructional media is not only visually appealing but also intuitively operable and effective in achieving specific pedagogical goals (Luckin et al., 2006). Implementing standardized evaluation metrics, such as the System Usability Scale (SUS), is vital for measuring the actual accessibility and acceptance of the media among students. Previous research suggests that instructional tools with high usability scores correlate positively with the efficiency of knowledge retention and student satisfaction (Vlachogianni & Τσέλιος, 2023). Therefore, a dual focus on expert-validated content and user-centered technical functionality is a prerequisite for any successful digital learning intervention. This holistic approach ensures that the developed game not only effectively teaches algorithmic thinking but also provides an engaging and accessible platform for Grade VIII Informatics students (Rohmatulloh & Hasanah, 2026).

This study aims to develop and evaluate "*Algamerithm*", an interactive educational game designed with a human-centric approach to facilitate the mastery of basic algorithms using the ADDIE development model. Through this application, students are challenged to navigate logical puzzles that mirror real-world algorithmic sequences, thereby transforming abstract concepts into tangible interactive experiences. The primary focus of this research is to validate the media's feasibility through expert assessment and to empirically measure its impact on student learning outcomes by comparing experimental and control groups. The findings are expected to provide both a theoretical contribution to the field of interactive media and a practical solution for vocational educators seeking to enhance student proficiency in basic programming.

2 Methodology

2.1 Research Framework and Design

This study employs the Research and Development (R&D) methodology, specifically adopting the ADDIE (Analysis, Design, Development, Implementation, Evaluation) instructional design model to engineer a scientifically validated educational tool, as illustrated in Figure 1. The ADDIE framework is widely recognized as a robust, systematic paradigm that guides the development process from initial problem identification through to the final assessment of educational efficacy (Shakeel et al., 2022). This iterative approach is particularly effective in facilitating the structured integration of digital resources to meet contemporary educational demands (Abuhassna et al., 2024; Syahrizal et al., 2024). The selection of the ADDIE model is highly pertinent given its comprehensive nature, making it exceptionally well-suited for crafting interactive self-instructional modules and digital learning materials (Gunadi et al., 2025; Torrefranca, 2017).

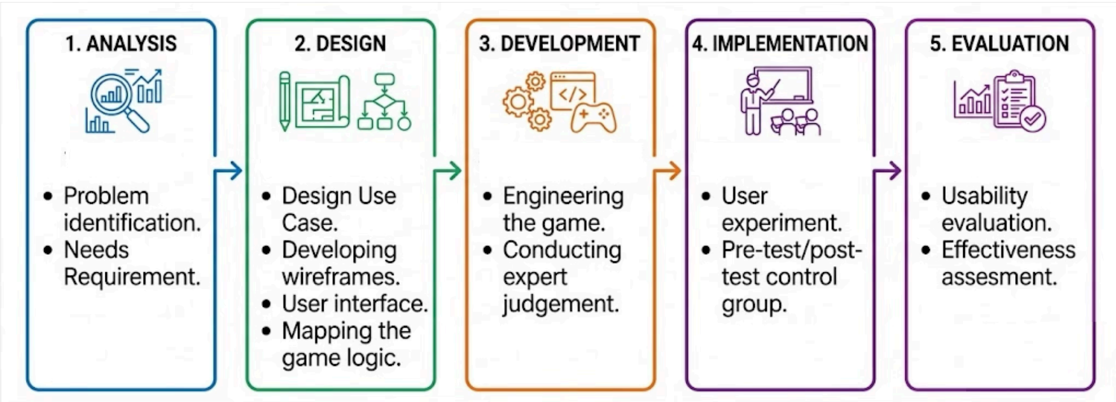

Figure 1. The ADDIE model for the stages in this study

During the Analysis phase, a preliminary field study conducted at a vocational school revealed that reliance on conventional lectures and static PowerPoint presentations resulted in significant student passivity and a lack of engagement with abstract algorithmic concepts. This initial assessment established a critical pedagogical requirement for a more interactive, visually dynamic solution capable of bridging the gap between theoretical logic and practical comprehension. Consequently, the research objective was refined not merely to construct a game, but to develop a human-centric educational medium that resonates with the digital-native characteristics of vocational students. This foundational analysis ensured that the subsequent intervention addresses identified learner needs and instructional goals, aligning with the principles of established educational games like JUSECA and SplashCode (Angulo & Castro, 2022; Dhananjaya & Haryani, 2023; Nuntawisuttiwong & Dejdumrong, 2024; Wangenheim et al., 2019).

The Design phase focused on conceptualizing the "*Algamerithm*" application to systematically address the challenges identified during the analysis. In this stage, learning objectives and game mechanics were meticulously formulated to foster active engagement with algorithmic principles. To ensure user interactions were intuitive and aligned with a Human-Centric Design approach, the system architecture was comprehensively mapped using Use Case and Activity Diagrams. This structured planning phase is crucial for ensuring that the educational software effectively targets specific learning gaps and promotes active, self-directed learning through gamification, seamlessly integrating curriculum-aligned content into the gameplay experience (Aras & Can, 2023; Sriyanto & Dianastiti, 2025).

Following the design specifications, the Development phase utilized the Construct 2 engine to realize the 2D interactive environment of the game. This engine enabled the creation of a platformer-style game that introduces algorithmic materials in a progressive, interactive manner with easily navigable interfaces. During this phase, the product underwent rigorous internal testing, notably Blackbox Testing, to verify that all functional requirements, such as level navigation and score tracking, operated flawlessly without technical anomalies. Furthermore, the iterative nature of the ADDIE framework facilitated expert-led refinements utilizing Aiken's V for content and construct validation prior to classroom introduction. This systematic progression ensures the final product is not only technologically functional but also educationally impactful for introductory programming students.

2.2 Participants and Research Setting

The implementation phase of this research involved a total of 30 students from the Grade X Multimedia class at a vocational school. The selection of this specific group was based on their current curriculum requirements, which include "*Basic Programming*" as a foundational competency where algorithmic logic is first introduced. To ensure a balanced and representative evaluation of the human-centric design, the participants were categorized based on gender, age, and prior experience with similar educational technology. The demographic details of the research participants are presented in Table 1.

Table 1. Demographic profile of the research participants

	Category	Frequency	Percentage (%)
Gender	Male	15	50%
	Female	15	50%
Age	14 years old	2	6.70%
	15 years old	13	43.30%
	16 years old	15	50%
Prior Experience	Ever used similar apps	0	0%
	Never used similar apps	30	100%
Total		30	100%

The data in Table 1 highlights a critical "knowledge gap" since 100% of the participants had never interacted with similar game-based learning media for algorithms. This condition provides an ideal environment for testing the "Algamerithm" application, as it allows the researchers to measure the media's impact on absolute beginners without prior bias from other digital tools. Furthermore, the balanced gender distribution (50% male and 50% female) ensures that the usability results from SUS reflect a universal experience across the vocational student population at the research site.

2.3 Instruments and Analytical Techniques

To ensure the scientific rigor of the developed media, this study utilized three primary evaluation instruments. First, the content and media validity were assessed by four experts (two media specialists and two subject matter experts) using an instrument analyzed through Aiken's V coefficient. Second, the human-centric aspect was quantified using the SUS. The SUS is a globally recognized 10-item Likert scale used to measure the usability and user acceptance of the "*Algamerithm*" educational game. The specific indicators used in this study are detailed in Table 2.

Table 2. SUS indicators for the developed game evaluation

Item ID	Usability Indicators (Items)
Q1	I think that I would like to use this educational game frequently.
Q2	I found the educational game unnecessarily complex.
Q3	I thought the educational game was easy to use.
Q4	I think that I would need the support of a technical person to be able to use this game.
Q5	I found the various functions in this educational game were well integrated.
Q6	I thought there was too much inconsistency in this educational game.

Item ID	Usability Indicators (Items)
Q7	I would imagine that most people would learn to use this game very quickly.
Q8	I found the educational game very cumbersome (confusing) to use.
Q9	I felt very confident using the educational game.
Q10	I needed to learn a lot of things before I could get going with this game.

The impact on student learning performance was analyzed through a pre-test and post-test design. Quantitative data were subjected to several statistical tests, including Normality and Homogeneity tests. To determine if there was a significant difference between the two instructional methods, an Independent Sample T-test was conducted. Finally, the effectiveness level was measured using the Normalized Gain (N-Gain) score.

3 Results and Discussion

3.1 Algamerithm Educational Game

The game developed in this research is named *Algamerithm*, designed specifically to introduce foundational programming concepts through an intuitive graphical interface. As depicted in Figure 2, the environment utilizes a warm, visually engaging desert motif that aims to reduce the anxiety often associated with learning complex technical subjects. This aesthetic choice is deeply rooted in the Human-Centric Design (HCD) framework, which prioritizes the emotional and cognitive well-being of the learner during the interaction process (Dell'Aquila et al., 2025). The interface features a prominent leftmost panel structured to hold a sequence of commands, thereby mirroring the chronological execution found in traditional coding environments. By transforming abstract code syntax into tangible visual blocks, the application successfully lowers the barrier to entry for novice learners navigating basic algorithms.

The core gameplay mechanics revolve around guiding a central avatar across a strategically arranged grid of wooden platforms to reach a predefined goal, symbolized by a star. Users must utilize a specific set of action commands, namely "WALK", "LEFT", "RIGHT", and "LOOPING", to construct a logical pathway for the character. Integrating the "LOOPING" function is particularly critical, as it introduces users to iteration and computational efficiency without overwhelming them with text-based syntax (Li & Tzu-Chuen, 2023). This step-by-step problem-solving process naturally cultivates algorithmic thinking, requiring players to mentally simulate the character's movement before executing the sequence. Furthermore, the placement of collectible coins along the path serves as micro-rewards, encouraging learners to not only find a working solution but to seek the most optimal and rewarding route.

To further align with the principles of effective interactive learning media, Algamerithm incorporates dynamic feedback mechanisms such as a real-time score and a countdown timer. The inclusion of a scoring system provides immediate positive reinforcement when users successfully collect coins or reach the ultimate objective. Meanwhile, the timer introduces a moderate level of challenge, prompting learners to optimize their cognitive processing speed while constructing their algorithmic sequences. Recent studies on gamified learning environments emphasize that balancing challenge and skill through such constraints significantly enhances user engagement and prevents cognitive boredom in computer science education (Coelho et al., 2025). Through these carefully calibrated gamification elements, the system ensures that the learner remains actively focused on the task. Consequently, the application transforms a potentially tedious cognitive exercise into an immersive and highly interactive educational experience.

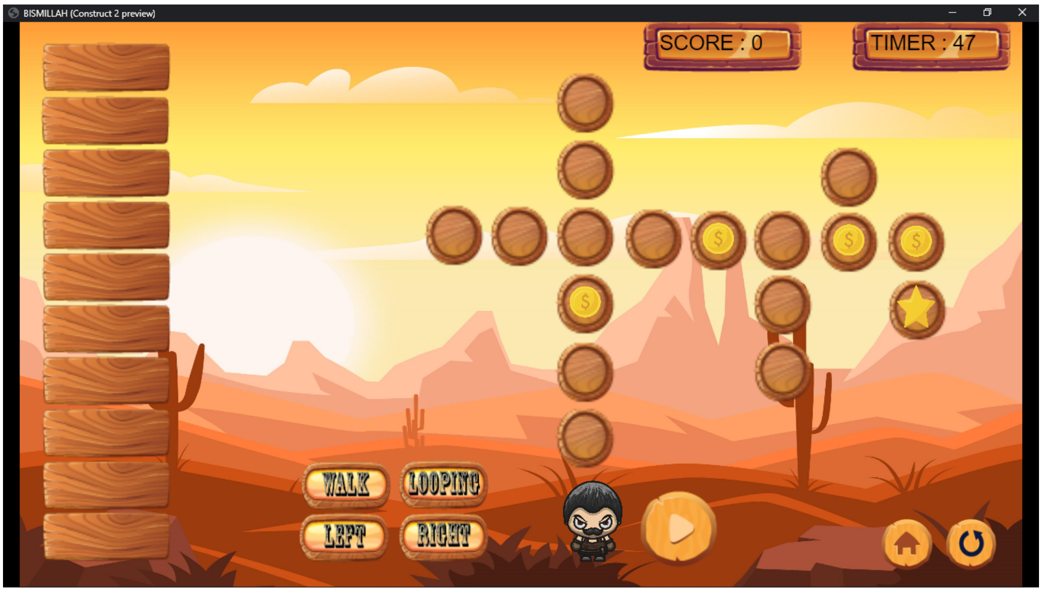

Figure 2. Main scene of algamerithm educational game

Ultimately, the design and implementation of Algamerithm strongly reflect a Human-Centric Design approach tailored for interactive educational technology. Every element on the screen, from the distinct typography of the command buttons to the clear visual feedback of the character's progression, was engineered with the end-user's cognitive load in mind. By avoiding cluttered interfaces and focusing strictly on the essential mechanics of directional logic and looping, the game maintains a high degree of pedagogical clarity. Current literature suggests that such focused, learner-centric methodologies yield significantly higher retention rates in early programming education compared to traditional rote learning methods (Lee et al., 2023). Therefore, Algamerithm stands as a robust proof-of-concept demonstrating how thoughtful, human-centered interactive media can successfully guide students in mastering fundamental algorithms.

3.2 Usability and Effectiveness Evaluation

To evaluate the user satisfaction of the developed game, a usability testing phase was conducted involving 30 diverse participants who completed the standardized SUS. As presented in Table 3, the calculation of the SUS instrument reveals the detailed score recapitulation derived from the ten standard usability questions. The cumulative analysis of these raw responses yielded a final average usability score of 64.4 out of 100. Within the established SUS evaluation metrics, a score of 68 represents the global average, placing it in the ”Marginal” or borderline ”Acceptable” category. This quantitative outcome indicates that while the educational game is functionally viable for basic interactions, there remains a critical need for targeted design interventions to elevate the overall user experience.

Despite falling slightly below the universal average, the detailed breakdown of the SUS data highlights several core strengths in the current design of the interactive learning media. The highest converted usability scores were recorded for Question 4 (86.7) and Question 8 (82.5), providing valuable insights into user independence and system fluidity. Specifically, the exceptionally high score on Question 4 demonstrates that the vast majority of participants felt confident playing the game without requiring external technical support or continuous assistance from an instructor. Furthermore, the strong result on Question 8 indicates that users did not perceive the system's interface as cumbersome or unnecessarily complex to navigate. These positive outcomes validate the implementation of the Human-Centric Design approach, proving that translating abstract syntax into tangible visual blocks successfully creates a highly intuitive environment for novice programmers.

Conversely, a critical analysis of the lowest-performing metrics provides clear, objective directives for future system refinement and iterative development. The evaluation data indicates notable usability challenges primarily concerning Question 10 (37.5) and Question 7 (44.2). The particularly low score on

Question 10 suggests that users felt they needed to learn a considerable amount of preliminary information before they could comfortably and independently engage with the gameplay. Additionally, the suboptimal results from Question 7 imply a perception among some participants that certain interactive features or mechanics felt disjointed or inadequately integrated for beginners. This phenomenon is logically sound considering the target audience; introducing abstract computational concepts like ”Looping” to absolute beginners can rapidly induce cognitive overload if not preceded by a carefully scaffolded interactive introduction.

Table 3. SUS Score evaluation

Questions No.	Raw	SUS Score 0-4	SUS Score 0-100
1	3.53	2.53	63.3
2	2.13	2.87	71.7
3	3.4	2.4	60
4	1.53	3.47	86.7
5	3.77	2.77	69.2
6	2.27	2.73	68.3
7	2.77	1.77	44.2
8	1.7	3.3	82.5
9	3.43	2.43	60.8
10	3.5	1.5	37.5
Total			64.4

Synthesizing these empirical findings, it becomes evident that the primary usability barriers are not rooted in the core gameplay mechanics, but rather in the initial user onboarding experience. Achieving a baseline score of 64.4 serves as a highly constructive starting point for an educational prototype, pinpointing exactly where future developmental resources should be strategically allocated. To directly address the steep initial learning curve highlighted by Question 10, future iterations of the software must integrate a progressive onboarding phase or a series of guided, micro-step tutorial levels. Implementing these targeted pedagogical improvements aligns perfectly with the iterative nature of the Human-Centric Design framework, ensuring that the system continually adapts to the cognitive limitations of its users. By bridging this specific experiential gap, the subsequent version of Algamerithm is poised to achieve significantly higher usability, thereby maximizing its potential as an engaging tool for mastering basic algorithms.

The effectiveness of the game was further evaluated through a pretest and posttest scores between the experimental and control groups, as shown in Table 4. In the experimental group, which utilized the game, the average student score increased significantly from 68.06 during the pretest to 89.46 in the posttest phase. In contrast, the control group that received conventional lecture-based instruction showed a much smaller improvement, moving from an initial average of 68.40 to only 74.13. This substantial disparity highlights the superiority of interactive game-based learning over traditional methods in helping students grasp abstract programming logic. Statistical analysis through the Independent Sample T-test yielded a significance value of 0.000, which is well below the 0.05 threshold, thereby confirming a statistically significant difference in learning outcomes.

Table 4. Pretest and posttest scores

Group	Average Pretest	Average Posttest	Mean	N-Gain (%)	Effectiveness
Control Group	68.4	74.13	5.73	18.52%	Ineffective
Experimental Group	68.06	89.46	21.4	63.86%	Moderately Effective

To determine the magnitude of the learning improvement, a Normalized Gain (N-Gain) test was conducted for both research groups. The experimental group achieved an N-Gain score of 63.86%, which is classified as ”Moderately Effective” in enhancing students' understanding of basic algorithms. Conversely, the control group only attained an N-Gain score of 18.52%, placing it in the ”Ineffective” category for significant knowledge acquisition. These findings demonstrate that the integration of game mechanics with learning objectives provides a more impactful environment for cognitive development than passive observation. The data indicates that the structured levels and immediate feedback within *Algamerithm* facilitate a more efficient transition from basic to complex logical concepts.

3.3 Discussion

The integration of a Human-Centric Design (HCD) approach in the developed educational game serves as a foundational strategy to alleviate the cognitive difficulties commonly associated with basic algorithm instruction. By employing an engaging desert motif, the learning environment is intentionally structured to reduce student anxiety while navigating complex technical subjects. Furthermore, the application successfully lowers the barrier to entry for novice programmers by transforming abstract, text-based code syntax into tangible visual blocks. This strategic design decision ensures that students can focus entirely on the essential mechanics of directional logic and looping without experiencing unnecessary cognitive overload. Consequently, such focused, learner-centric methodologies have been shown to yield significantly higher retention rates in early programming education compared to traditional rote learning methods (Lee et al., 2023).

Beyond the visual interface, the implementation of dynamic gamification elements further solidifies the game's human-centric pedagogical value. The system incorporates real-time feedback mechanisms, such as a scoring system and a countdown timer, to provide immediate positive reinforcement during the problem-solving process. By challenging learners to optimize their cognitive processing speed against a timer, the game introduces a moderate level of difficulty that continually maintains user focus. Recent studies emphasize that balancing challenge and skill through such constraints significantly enhances user engagement and prevents cognitive boredom in computer science education (Coelho et al., 2025). Ultimately, these carefully calibrated mechanics transform a potentially tedious cognitive exercise into an immersive and highly interactive educational experience.

The empirical evaluation of the game's usability provided critical insights into the user experience, yielding an average SUS score of 64.4 out of 100. Detailed analysis of the SUS metrics revealed significant strengths in user independence, with exceptionally high scores indicating that participants felt confident playing without requiring continuous instructor support. Additionally, users did not perceive the system's interface as cumbersome or unnecessarily complex, thereby validating the intuitive nature of the visual programming blocks. However, the evaluation also highlighted specific usability barriers, particularly a steep initial learning curve where users felt they needed preliminary information before comfortably engaging with the gameplay. To directly address this limitation and align perfectly with the iterative nature of the HCD framework, future versions of the software must integrate a progressive onboarding phase or guided micro-step tutorial levels.

In terms of pedagogical effectiveness, the interactive game demonstrated a substantial impact on student learning outcomes when compared directly to conventional teaching methodologies. The experimental group utilizing the interactive media experienced a significant average score increase from 68.06 in the pretest to 89.46 in the posttest phase. Conversely, the control group receiving traditional lecture-based instruction showed a much smaller improvement, moving from 68.40 to only 74.13. This substantial disparity, statistically confirmed by an Independent Sample T-test significance value of 0.000, highlights the clear superiority of interactive game-based learning over traditional methods in grasping abstract programming logic. Furthermore, the experimental group achieved a Normalized Gain (N-Gain) score of 63.86%, classifying the intervention as ”Moderately Effective” in enhancing students' understanding of basic algorithms, while the control group remained in the ”Ineffective” category at 18.52%.

Synthesizing the usability and effectiveness outcomes confirms that integrating a Human-Centric

Design approach within educational games offers a highly viable solution for teaching foundational algorithms. The empirical data strongly indicates that the structured levels and immediate feedback within the game facilitate a more efficient transition from basic to complex logical concepts. Although the overall usability score of 64.4 indicates a functional system that requires future targeted onboarding refinements, the highly significant learning gains demonstrate its immediate and practical value in the classroom. These findings prove that aligning instructional delivery with the characteristics of digital-native students through interactive visual stimuli effectively bridges the critical gap between traditional teaching and student engagement. Therefore, this dual focus on user-centered technical functionality and measurable academic effectiveness ensures that the developed game successfully cultivates essential problem-solving capabilities in vocational informatics students.

4 Conclusion

This study evaluated the usability and effectiveness of an educational game *Algamerithm* integrating a HCD approach to facilitate the learning of basic algorithms among vocational students. By transforming abstract programming syntax into intuitive visual blocks, the game effectively lowered the cognitive barrier for novice learners. Empirical findings demonstrated that the game-based intervention was significantly more effective than traditional teaching methods, achieving a moderately effective N-Gain score of 63.86% compared to the control group's 18.52%. Furthermore, the usability evaluation yielded an average SUS score of 64.4, indicating that the system is functionally viable and promotes high user independence without requiring continuous technical support. Ultimately, the integration of HCD principles within this interactive media not only successfully engaged digital-native students but also substantially improved their mastery of foundational programming logic.

Despite these positive outcomes, this study acknowledges certain limitations that provide clear, objective directives for future research and iterative development. The primary usability barrier identified was a steep initial learning curve, as the evaluation data indicated that users felt they needed preliminary information before they could comfortably and independently engage with the gameplay. Consequently, future iterations of the educational game should prioritize the development of a progressive onboarding phase or guided micro-step tutorial levels to further enhance the initial user experience. Additionally, subsequent studies should evaluate the game across broader and more diverse student populations. Expanding the demographic scope and refining the onboarding process aligns perfectly with the iterative nature of the HCD framework, ensuring the system continually adapts to maximize its potential as an engaging educational tool.

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