IELTech Informatics Education and Learning Technologies

Vol 1, No. 1, June 2025, pp. 31–41
doi: 10.23917/ieltech.v1i1.16607

Development and Usability Evaluation of Augmented Reality-Based Learning Media for Introducing Algorithm Concepts

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Article History:

Received: 13 February 2025
Revised: 8 April 2025
Accepted: 12 May 2025
Published: 4 June 2025

Keywords:

Augmented Reality, algorithm concepts, flowchart, learning media, usability evaluation, System Usability Scale

Abstract

The teaching of algorithm concepts to novice learners presents persistent challenges due to the abstract nature of computational thinking and the difficulty of visualizing sequential processes. This study aimed to develop and evaluate the usability of an Augmented Reality-based learning medium for introducing algorithm concepts to tenth-grade students. The research employed the Multimedia Development Life Cycle (MDLC) methodology, encompassing concept, design, material collecting, assembly, testing, and distribution stages. The resulting Android application integrates physical flowchart cards with interactive three-dimensional animations, where students arrange cards in correct sequences to trigger animated characters that visually demonstrate algorithm execution. The application was validated by two media experts and one subject matter expert, then evaluated by 38 tenth-grade students using the System Usability Scale (SUS). Expert validation results showed mean Aiken's V coefficients of 0.93 for both media and material experts, with feasibility percentages of 94.4% and 95% respectively, categorizing the product as very feasible. Black box testing confirmed 100% functional success across all application features. The user evaluation yielded a mean SUS score of 71.31, which corresponds to a Grade of C+, an adjective rating of "Good," and falls within the "Acceptable" range according to Sauro's interpretation framework. Notably, 94.7% of participants had no prior experience with similar AR applications, indicating that usability was achieved despite technological novelty. Qualitative feedback revealed positive student engagement and appreciation for the interactive visualization approach. This study concludes that the developed AR learning medium is feasible and acceptable for introducing algorithm concepts, transforming abstract flowchart logic into observable, interactive experiences that support foundational computational thinking development.

1 Introduction

The rapid advancement of digital technologies has fundamentally transformed educational landscapes, particularly through the integration of immersive technologies that bridge the gap between abstract concepts and tangible understanding. Among these emerging technologies, Augmented Reality (AR) has garnered significant attention from educators and researchers due to its unique capacity to overlay digital information onto physical environments, thereby creating interactive learning experiences that were previously unattainable through conventional methods (Prananta, 2025). In the context of Education 5.0, which emphasizes human-centric, technology-enhanced learning environments, AR stands out as a pedagogical tool capable of addressing longstanding challenges in teaching complex and abstract subject matter (Jagatheesaperumal et al., 2024). As educational institutions worldwide seek to prepare students for an increasingly digital future, the exploration of AR's potential to support meaningful learning outcomes has become both timely and critical.

The teaching of algorithmic thinking and programming concepts presents particular pedagogical challenges, especially for novice learners at the secondary education level (Nijenhuis-Voogt et al., 2023). Algorithmic thinking, which involves the ability to formulate problems and express their solutions through systematic, step-by-step procedures, represents a fundamental competency in computer science education (Toledo et al., 2023). However, introductory algorithm instruction often relies heavily on text-based representations, abstract symbols, and diagrammatic notations such as flowcharts, which can be difficult for students to internalize and connect with concrete problem-solving scenarios. Research indicates that students new to programming frequently struggle with visualizing how algorithms execute and how data transforms through sequential operations, leading to disengagement and misconceptions that hinder subsequent learning (Qian & Lehman, 2017). These difficulties stem partly from the cognitive load imposed when learners must simultaneously grasp abstract rules while imagining dynamic processes that are not explicitly visible in static textbook representations.

AR offers a promising solution to these pedagogical challenges by enabling the visualization of abstract computational concepts through interactive three-dimensional representations (Schez-Sobrino et al., 2021). When applied to algorithm education, AR can transform static flowchart symbols into dynamic animations that demonstrate the flow of logic and data transformation in real-time (Paredes-Velasco et al., 2023). This capacity for externalizing mental models aligns with contemporary learning theories emphasizing embodied and situated cognition, where understanding is enhanced through perceptual and interactive engagement with conceptual content (Prananta, 2025). Recent systematic reviews have confirmed that AR applications in education consistently demonstrate positive effects on student motivation, engagement, and learning outcomes across various disciplines, including science, mathematics, and engineering education (Paredes-Velasco et al., 2023). The technology's ability to provide immediate visual feedback and support exploratory learning makes it particularly well-suited for subjects that require understanding of sequential processes and logical structures (Briceno, 2025).

Despite the growing body of research on AR in education, the specific application of this technology to algorithm instruction at the high school level remains relatively underexplored. While numerous studies have investigated AR for teaching programming through block-based languages or robotics (Çipiloğlu Yıldız & Doğan, 2024), fewer have focused on supporting the foundational conceptual understanding of algorithms themselves prior to coding implementation. This gap is significant because algorithmic thinking serves as the prerequisite for effective programming, and difficulties at this conceptual stage can cascade into broader challenges with computational problem-solving (Doleck et al., 2017). Furthermore, existing AR learning media often provide passive viewing experiences where students observe pre-programmed animations rather than actively constructing and testing algorithmic solutions (Çipiloğlu Yıldız & Doğan, 2024). There is a demonstrated need for interactive AR environments that engage students in the process of algorithm construction while providing concrete visualizations of the consequences of their design choices.

The present study addresses this gap by developing and evaluating an AR-based learning medium specifically designed to introduce algorithm concepts to tenth-grade students. Drawing upon established principles of multimedia learning and human-computer interaction, the proposed application combines tangible interaction through physical flowchart cards with AR-generated three-dimensional animations that respond to students' algorithmic constructions. This approach transforms abstract flowchart symbols into manipulable objects whose arrangement determines the behavior of animated characters, thereby making the relationship between algorithmic structure and computational outcomes perceptually accessible. By integrating puzzle-based mechanics with AR visualization, the design aims to reduce cognitive load while promoting active experimentation and conceptual understanding. The research was guided by two primary questions:

(1) How can AR be utilized to create effective learning media for introducing algorithm concepts? and

(2) What is the usability of the developed AR learning medium as assessed by media experts, subject matter experts, and target users?

2 Method

2.1 Research Design

This study employed a Research and Development (R&D) approach utilizing the Multimedia Development Life Cycle (MDLC) (Rahayu & Dewi, 2018), which consists of six sequential stages: *concept, design, material collecting, assembly, testing*, and *distribution*. This model was selected because it provides a systematic framework specifically tailored for multimedia product development, ensuring that each phase of the development process receives adequate attention before proceeding to subsequent stages. The research focused on developing an AR-based learning medium for introducing algorithm concepts to tenth-grade students.

2.2 Development Procedure and Product Specifications

The development process began with the *concept* stage, which established the learning objectives, target users (tenth-grade students), and core interaction concept. The fundamental idea was to integrate AR technology with puzzle-based gameplay, where students arrange physical flowchart cards in correct sequences to trigger corresponding 3D animations. This approach was designed to make the abstract nature of algorithmic thinking more concrete and observable through visual feedback.

In the *design* stage, the application architecture was planned through use case diagrams, activity diagrams, and storyboards. The application was designed for the Android platform with five main menus: Start AR, Materials, Instructions, About, and Profile. The *Start AR* menu functions as the core feature, displaying the AR camera view where users scan arranged flowchart cards to visualize algorithm execution through animated 3D objects.

The *material collecting* stage involved gathering all necessary components. Algorithm materials were sourced from the official tenth-grade Informatics textbook. Three-dimensional objects and animations were created using Blender software, while user interface elements including buttons, backgrounds, and icons were designed using Adobe XD and Adobe Photoshop. The AR marker database was developed through the *Vuforia* developer platform, with flowchart symbols serving as image targets.

During the *assembly* stage, all components were integrated using Unity 3D game engine. The flowchart markers were imported from the Vuforia database, and 3D objects with their associated animations were linked to specific marker configurations. The application was programmed to recognize when users had arranged flowchart cards in a logically correct sequence, triggering the corresponding animation that visually demonstrated the algorithm's execution. The final product was compiled into an Android application package (.apk) format.

The resulting application is an Android-based AR learning medium focused on algorithm concepts, specifically flowchart sub-materials. It contains educational content including definitions, functions, types, symbols, and examples of flowcharts. The AR feature displays 3D animated characters that respond to correctly arranged flowchart card sequences, providing immediate visual feedback on algorithmic logic. Users can interact with the 3D objects through zoom in and zoom out functions.

The *testing* stage employed black box testing to verify that all functional elements operated correctly. This testing examined whether each button, menu navigation, and AR feature performed as intended without examining internal code structure. The final distribution stage produced the completed application ready for implementation and evaluation with target users.

2.3 Participants

The user evaluation involved 38 tenth-grade students who participated as target users of the developed AR learning medium, as provided in Table 1. The participant demographics included 17 male students (44%) and 21 female students (56%), with ages ranging from 15 years (37%) to 16 years (63%). Notably, 96% of participants reported having no prior experience with similar AR applications, indicating that the medium represented a novel learning experience for most students. Additionally, two media experts (lecturers in Informatics Education) and one subject matter expert (Informatics teacher) served as validators to assess the quality and feasibility of the developed application prior to user testing.

Table 1: Participant demographics

Participants	Category	n	%
Gender	Male	17	44
	Female	21	56
Total		**38**	**100**
Age	15 years	14	37
	16 years	24	63
Total		**38**	**100**
Experience using similar applications?	Yes	**4**	**4**
	No	**34**	**96**
Total		**38**	**100**

2.4 Data Collection and Analysis Techniques

Three types of instruments were employed for data collection. Media expert validation instruments consisted of 18 items across three aspects: learning design, visual communication, and software functionality. Material expert validation instruments comprised 16 items covering learning content and visual communication aspects. Both validation instruments utilized a five-point Likert scale (1 = strongly disagree to 5 = strongly agree). User evaluation instruments employed the System Usability Scale (SUS) (Brooke, 1996), which consists of 10 standardized statements with five-point Likert scales. The SUS was selected because it provides a reliable, industry-standard measure of perceived usability applicable across diverse product types including educational applications, and it has been widely used in AR educational research.

Data analysis employed three complementary techniques. Aiken's V validity coefficient was calculated for expert validation items to determine the content validity of each instrument item using the formula:

$$V = \frac{\sum s}{[n(c-1)]}$$

where $s=r-lo$, r is the rater's score, lo is the lowest validity rating (1), n is the number of raters, and c is the highest validity rating (5). Items were considered valid if the V value exceeded the Aiken's table limit for the corresponding number of items and raters.

Percentage interpretation analysis was applied to expert validation data to determine the feasibility level of the developed product using the formula:

$$Feasibility\ percentage = \frac{obtained\ score}{maximum\ score}\ x\ 100\%$$

Results were categorized into five levels: very feasible (81-100%), feasible (61-80%), moderately feasible (41-60%), less feasible (21-40%), and not feasible (0-20%).

SUS analysis followed the standardized scoring procedure for user evaluation data. For odd-numbered items (1,3,5,7,9), the contribution score was calculated as the scale position minus 1. For even-numbered items (2,4,6,8,10), the contribution score was 5 minus the scale position. Individual participant scores were summed and multiplied by 2.5 to obtain a SUS score ranging from 0 to 100. The mean score across all participants was calculated and interpreted according to Sauro's grading scale, which includes acceptability ranges (not acceptable, marginal, acceptable), adjective ratings (worst imaginable to best imaginable), and grade assignments (F to A+).

3 Results and Discussion

3.1 Product Development

The research successfully produced an AR-based learning medium for introducing algorithm concepts. The final product is an Android application package (.apk) focused on flowchart material as the foundational concept in algorithm education. The application features five main menus: Start AR, Materials, Instructions, About, and Profile, as provided in Figure 1 (a).

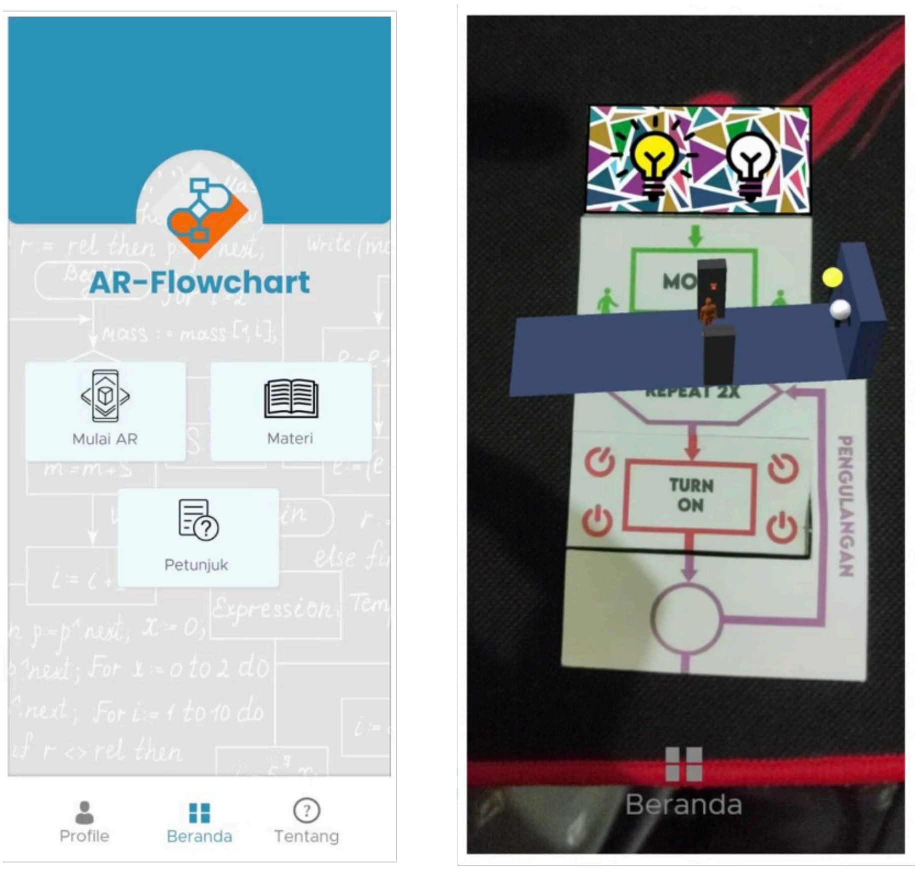
The Start menu serves as the core functionality, displaying the camera view where users scan physical flowchart cards. When cards are arranged in a logically correct sequence, the application recognizes the configuration through the Vuforia database and displays corresponding three-dimensional animations (Figure 1b). These animations visually demonstrate algorithm execution through character movements and interactions, making abstract flowchart logic concretely observable. Users can interact with the displayed 3D objects using zoom in and zoom out functions to examine details from different perspectives.

The Materials menu contains comprehensive flowchart learning content organized into five sub-sections: definition of flowcharts, functions of flowcharts, types of flowcharts, flowchart symbols, and examples of flowchart applications. All content was aligned with the tenth-grade Informatics curriculum to ensure educational relevance. The Instructions menu provides guidance on using the AR features, including how to arrange flowchart cards and download printable marker cards through an integrated link. The About menu presents information about the application's purpose and learning objectives, while the Profile menu displays developer information. The detail application features and specifications can be seen in Table 2.

Table 2: Application features and specifications

Feature	Description
Platform	Android
Core Material	Flowchart concepts (definitions, functions, types, symbols, examples)
Main Menus	Start AR, Materials, Instructions, About, Profile
AR Interaction	Marker-based with physical flowchart cards
3D Output	Animated characters demonstrating algorithm execution

Feature	Description
Additional Functions	Zoom in, zoom out, card download link
File Format	.apk (Android application package)



(a) (b)

Figure 1: (a) Main menu of the application, (b) AR feature is running

3.2 *Black Box Testing and Expert Validation Results*

Functional testing was conducted to verify that all application components operated as intended. Eleven test cases were executed covering all main menus, navigation buttons, and AR functionality. Each test case involved specific user actions with corresponding expected outcomes. The testing confirmed that all buttons correctly navigated to the intended pages, the AR camera successfully detected markers and displayed 3D objects, zoom functions operated properly, and the marker download link functioned correctly. All eleven test cases produced successful results, indicating that the application was functionally ready for expert validation and user testing. The results summary can be seen in Table 3.

Table 3: Black box testing results summary

Testing Component	Number of Test Cases	Successful	Failed	Success Rate
Main Menu Navigation	5	5	0	100%
AR Camera Functions	3	3	0	100%
Materials Menu	2	2	0	100%
Instructions Menu	1	1	0	100%
Total	**11**	**11**	**0**	**100%**

Two media experts (lecturers in Informatics Education) evaluated the application across 18 items covering three aspects: learning design, visual communication, and software functionality. Each item was rated on a five-point Likert scale. Aiken's V validity coefficient was calculated for all items to determine content validity. The results showed V values ranging from 0.75 to 1.00 across the 18 items, with the lowest value (0.75) occurring for one item in the software functionality aspect. All V values exceeded the Aiken's table lower limit of 0.69 for 18 items with two raters, confirming that all items were valid. The mean V coefficient across all items was 0.93, indicating excellent content validity.

The total score obtained from media experts was 170 out of a maximum possible 180, yielding a feasibility percentage of 94.4%. According to the interpretation criteria, this falls within the "very feasible" category (81-100%). Media experts provided several constructive suggestions for improvement, including adding learning outcome statements, providing distinctive icons for different material options, maintaining button layout consistency, adding feedback mechanisms for AR interactions, improving the quality of AR cards, and adding more variations to the AR flowchart sequences.

One subject matter expert (Informatics teacher) evaluated the application across 16 items covering learning content and visual communication aspects. Aiken's V coefficient was calculated for each item. The results showed V values ranging from 0.75 to 1.00 across the 16 items, with three items receiving V = 0.75 and the remaining 13 items receiving V = 1.00. All V values exceeded the Aiken's table lower limit of 0.74 for 16 items with one rater, confirming that all items were valid. The mean V coefficient across all items was 0.93, indicating excellent content validity.

The total score obtained from the material expert was 76 out of a maximum possible 80, yielding a feasibility percentage of 95%. This falls within the "very feasible" category (81-100%). The material expert suggested writing the sources of flowchart symbols, further enriching the features, and enhancing the user interface design. The summary of expert validation results can be seen in Table 4.

Table 4: Summary of expert validation results

Validation Aspect	Number of Items	Number of Validators	Aiken's V Mean	Total Score	Maximum Score	Feasibility Percentage	Category
Media Expert	18	2	0.93	170	180	94.4%	Very Feasible
Material Expert	16	1	0.93	76	80	95%	Very Feasible

3.3 Usability Evaluation

The usability evaluation involved 38 tenth-grade students who completed the System Usability Scale (SUS) questionnaire after using the AR learning medium. The participant demographics included 17 male students (44.7%) and 21 female students (55.3%), with ages ranging from 15 years (36.8%) to 16 years (63.2%). Notably, 36 students (94.7%) reported having no prior experience with similar AR applications, indicating that the medium represented a novel learning experience for the vast majority of participants.

SUS scores were calculated following the standardized procedure. For odd-numbered items (1,3,5,7,9), the contribution score was the scale position minus 1. For even-numbered items (2,4,6,8,10), the contribution score was 5 minus the scale position. Individual scores were summed and multiplied by 2.5 to obtain SUS scores ranging from 0 to 100.

The individual SUS scores ranged from 52.5 to 82.5 across the 38 participants. The total sum of all SUS scores was 2,710, yielding a mean SUS score of 71.31. According to Sauro's interpretation framework, a mean score of 71.31 corresponds to a Grade of C+, an Adjective Rating of "Good," and falls within the "Acceptable" range for acceptability. This score exceeds the commonly referenced benchmark of 68, indicating that the system's usability is above average. The summary of the SUS results is provided in Table 5

Table 5: SUS results summary

Metric	Value
Number of Participants	38
Minimum Score	52.5
Maximum Score	82.5
Total Score	2,710
Mean Score	71.31
Grade (Sauro)	C+
Adjective Rating	Good
Acceptability	Acceptable

Qualitative feedback from student participants provided additional insights into their experiences with the application. Representative comments included:

"The application is quite good and interesting, easy to use, could be developed further to be more engaging." (Participant 8)

"Alhamdulillah, the program provided is quite easy to understand because it has the potential to facilitate or streamline a task/job." (Participant 23)

"The AR technology is very interesting, especially for learning. It's also the first time I've encountered AR being used in learning." (Participant 31)

"Good and creative application." (Participant 37)

These comments reflect positive reception of the AR learning medium, with students appreciating the novel approach to learning algorithm concepts through interactive AR technology. The feedback also aligned with quantitative SUS results, supporting the overall positive usability evaluation.

3.4 Discussion

The development of an Augmented Reality-based learning medium for introducing algorithm concepts represents a strategic response to the persistent pedagogical challenge of teaching abstract computational thinking to novice learners. The resulting application, which integrates physical flowchart cards with interactive 3D animations, successfully transformed static flowchart symbols into dynamic, observable processes that demonstrate algorithm execution through character movements and interactions. This approach directly addresses the core difficulty identified in algorithm education, where students struggle to visualize how sequential instructions produce computational outcomes (Giannakoulas & Xinogalos, 2025). By making the invisible logic of algorithms perceptually accessible, the AR medium embodies the principle that externalizing mental models through interactive visualization can reduce cognitive load and support conceptual understanding (Buchner et al., 2022). The puzzle-based mechanics, where students must arrange cards in correct sequences to trigger animations, further reinforces algorithmic thinking by requiring active construction rather than passive observation, distinguishing this design from many previous AR implementations that merely display pre-programmed content after marker scanning (Kao & Ruan, 2022).

The expert validation results, with feasibility percentages of 94.4% from media experts and 95% from material experts, provide strong evidence that the developed application meets established quality standards for educational multimedia. These exceptionally high ratings, coupled with Aiken's V coefficients of 0.93 for both validation groups, indicate that the instrument items appropriately measured the intended constructs and that expert judgment consistently affirmed the product's quality across learning design, visual communication, content accuracy, and technical functionality dimensions. Such validation outcomes align with previous AR development studies in educational contexts, where expert assessments typically range from 85% to 95% for products deemed suitable for implementation (Septana et al., 2020; Wahid et al., 2024). The specific suggestions provided by experts, including enhancing UI consistency, adding distinctive icons for material options, improving AR card quality, and incorporating more flowchart variations, offer valuable guidance for iterative refinement while confirming that the core conceptual design is fundamentally sound and educationally appropriate.

The mean System Usability Scale score of 71.31 obtained from 38 student participants carries meaningful implications when interpreted within the established SUS benchmarking framework. This score exceeds the widely cited threshold of 68, indicating that the system's usability is above average compared to the normative database of over 500 studies (Lewis & Sauro, 2021). The classification as ”Good” on the adjective rating scale and ”Acceptable” on the acceptability range further reinforces that students found the application intuitive, learnable, and practically useful for its intended educational purpose. This finding is particularly significant given that 94.7% of participants reported having no prior experience with similar AR applications, suggesting that the medium's usability was achieved despite the novelty of the technology for most users. The SUS results compare favorably with other AR educational applications, where reported SUS scores typically range from 65 to 75 for prototype-stage products, positioning this development within the upper quartile of usability performance for educational AR interventions.

The qualitative feedback from student participants provides complementary depth to the quantitative usability findings, revealing patterns of engagement and perceived learning value that warrant consideration. Comments describing the application as ”interesting,” ”easy to understand,” and ”creative” reflect affective responses that are crucial for sustained educational technology adoption, as positive attitudes toward learning tools correlate with increased motivation and deeper cognitive engagement (Kim et al., 2021). The observation from multiple students that this represented their first encounter with AR in educational contexts underscores the novelty value of this approach while simultaneously highlighting the untapped potential for broader AR integration in secondary education. Students' appreciation for how the technology ”facilitates understanding” and makes learning ”more engaging” aligns with theoretical frameworks positioning AR as a medium for bridging concrete and abstract representations through embodied interaction (Çipiloğlu Yıldız & Doğan, 2024). These qualitative insights suggest that beyond meeting usability benchmarks, the application successfully generated the kind of curiosity and interest that can transform passive reception into active exploration.

The integration of puzzle-based mechanics with AR visualization represents a distinctive contribution to algorithm education that extends beyond typical AR implementations. While much of the existing research on AR in programming education has focused on block-based coding environments or robot programming, this study specifically targeted the foundational conceptual understanding of algorithms themselves, independent of specific programming languages or execution environments. This focus is pedagogically significant because algorithmic thinking competencies transfer across programming languages and serve as prerequisites for effective coding practice (Wing, 2006). By enabling students to experiment with flowchart structures and immediately observe their behavioral consequences through animated characters, the application supports the development of mental models that students can subsequently apply when transitioning to text-based or block-based programming. This design philosophy aligns with contemporary understanding that computational thinking development benefits from multiple representational formats and opportunities for concrete manipulation before abstraction.

The findings from this development and evaluation study contribute to the growing body of evidence supporting AR's potential in computer science education specifically, and STEM education more broadly. The successful demonstration that an AR medium can achieve high usability ratings and expert validation while addressing the specific pedagogical challenge of algorithm visualization provides a model that can be adapted for other computational concepts requiring similar conceptual visualization support. Concepts such as recursion, data structures, and algorithm complexity, which share the characteristic of involving dynamic processes that are difficult to represent statically, may benefit from analogous AR approaches that externalize invisible processes through tangible interaction and animated visualization. As educational technology continues to evolve toward more immersive and interactive paradigms, the integration of AR with pedagogical principles derived from cognitive load theory and multimedia learning theory will become increasingly important for ensuring that technological capabilities translate into genuine learning improvements rather than mere novelty effects.

4 Conclusion

Based on the results and discussion, it can be concluded that the AR-based learning medium developed in this study is feasible and acceptable for introducing algorithm concepts to tenth-grade students. The application successfully translates abstract flowchart logic into observable three-dimensional animations through tangible card interactions, addressing the fundamental challenge of visualizing algorithmic processes. Expert validation confirmed the product's quality across learning design, content accuracy, and technical functionality dimensions, while user evaluation demonstrated above-average usability with a mean SUS score of 71.31, classified as ”Good” and ”Acceptable.” The positive reception from students, the majority of whom had no prior AR experience, indicates that the medium successfully engages learners and supports their understanding of algorithmic thinking through interactive visualization. This research contributes a validated AR-based approach to algorithm education that transforms passive reception of abstract concepts into active, observable experimentation, offering a pedagogical model applicable to other computational concepts requiring similar conceptual visualization support.

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