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Interactive mobile learning to improve computational thinking and achievement in digital systems courses

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ABSTRACT

The digital era has fundamentally transformed classroom instructional approaches, shifting the focus from completing subject matter to meaningful student engagement and active knowledge construction. Grounded in constructivist learning theory and principles of computational thinking, this study aims to examine the effectiveness of interactive mobile learning as a technology-enhanced instructional innovation in digital systems education. The innovation integrates multimedia, interactivity, and problem-based activities to support students' analytical and algorithmic reasoning. A quasi-experimental method was employed, involving 112 students enrolled in a digital systems course, with a nonequivalent control group pretest–posttest design. Data were analysed through multivariate analysis of covariance, independent T-tests, and N-gain analysis to evaluate learning effectiveness. The results revealed significant effects, both partial and simultaneous, with the experimental group consistently outperforming the control group. T-test findings indicated statistically significant differences between students using interactive mobile learning and those receiving conventional instruction. Furthermore, N-gain analysis showed improvements of 0.65 in computational thinking skills and 0.70 in learning achievement, categorised as medium to high gains. These findings confirm that interactive mobile learning effectively enhances learning outcomes. Therefore, it is recommended that educators integrate interactive mobile learning into digital systems instruction to foster students' computational thinking and academic achievement.

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INTRODUCTION

The evolution of learning in the digital era has profoundly transformed higher education. Artificial intelligence (AI) technology, learning analytics, and educational platforms and mobile devices promote more personalised, adaptive, and interactive learning (Behar et al., 2020; Fernández & Roa Martín, 2022; Ma & Li, 2021). Mobile technology supports learning systems that can adjust materials and levels of difficulty based on individual needs, while educational technologies ranging from Learning Management Systems (LMS), web-based simulations, to augmented/virtual reality provide means of visualisation and practice that were previously difficult to realise in a conventional classroom environment (Angraini et al., 2024; Anwar et al., 2024; Masruroh et al., 2024). The integration of this technology not only expands access and flexibility but also opens up opportunities for feedback, continuous assessment, and increased student engagement through a more contextual and meaningful learning experience (Su'uga et al., 2020; Subiki et al., 2023). This development is highly relevant to courses with a high level of abstraction, as it can bridge the gap between theoretical concepts and practical application (Muskhir et al., 2025).

Digital Systems courses play a central role in computer systems engineering education because they provide the conceptual foundation for understanding digital logic, network design, and hardware architecture underlying modern computing systems (Anwar et al., 2024; Tasrif et al., 2024). However, the abstract and conceptual nature of topics such as logic operations, number system transformations, and circuit simulations often creates significant learning difficulties when instruction relies primarily on lectures and textbooks (Jevanda BS et al., 2024). These challenges are reflected in relatively low student achievement and persistent difficulties in developing computational thinking skills, compounded by limited laboratory practice time, heterogeneous prior knowledge, and insufficient interactive learning resources capable of delivering immediate feedback and dynamic visualisation (Ardiansyah et al., 2024; Ekayana et al., 2024; Pratiwi & Santyasa, 2021); (Angraini et al., 2024; Bunyakul, 2022; Komalawardhana, 2021). Such conditions indicate an urgent need for instructional innovations that can bridge conceptual abstraction with experiential learning in digital systems education.

The development of mobile devices and digital pedagogy opens up opportunities to address these problems (Sari & Dantes, 2024). Interactive mobile learning combines multimedia, real-time simulations, adaptive quizzes, and feedback mechanisms that students can access anytime. The use of mobile phones and tablets that are already commonly owned by students supports the innovation of a mobile-based learning media that can increase accessibility, support independent learning, and provide a more concrete learning experience through logic animations, network simulations, and interactive exercises (Muskhir et al., 2025; Wiweka et al., 2024). Pedagogically, the interactive mobile learning approach is aligned with active learning theory and constructivism. Students become the leading actors in building knowledge through digital asset manipulation, authentic problem-solving, and reflection on the process (Budyastuti & Fauziati, 2021; Masgumelar & Mustafa, 2021). Good instructional design makes use of scaffolding from tutorials to open-ended tasks to support the transition from basic understanding to implementation. The development of innovations in the learning realm must consider the close relationship with the syllabus, learning objectives, and assessment instruments so that learning activities can be measured in their contribution to learning outcomes (Ardiansyah et al., 2024; Wu et al., 2022).

Although interactive mobile learning offers promising solutions to these instructional challenges, several important research gaps remain. Empirical studies that jointly examine its effects on computational thinking and academic achievement in Digital Systems courses are still scarce. In addition, validated, context-specific instruments for measuring computational thinking in digital systems learning are limited, and many existing mobile applications are poorly aligned with course syllabi or targeted competencies. These limitations limit the availability of strong evidence on the effectiveness of syllabus-integrated mobile learning, underscoring the need for focused research in this area.

A review of recent empirical studies suggests that interactive mobile learning has substantial potential to enhance higher education learning outcomes and advanced cognitive skills. The findings indicate that mobile learning integration can positively influence academic achievement and higher-order thinking processes (Sazen, 2020). Simulation-based mobile (SiM) learning environments have been shown to partially substitute laboratory experiences when designed with appropriate usability, task validity, and alignment with professional competencies (Juera, 2024). Furthermore, mobile learning interventions demonstrate positive effects on the development of computational thinking components such as problem decomposition, pattern recognition, and algorithmic reasoning compared with conventional instruction (Connolly et al., 2021). Nevertheless, prior studies generally examine these effects in isolation and rarely focus on Digital Systems courses with integrated curriculum alignment. This limitation highlights the novelty of the present study, which investigates a syllabus-integrated interactive mobile learning model and evaluates its combined effects on computational thinking skills and academic achievement.

Mobile learning, interactive media innovation in the Digital Systems course, is not only directed to present material more attractively but also to form a learning environment that encourages students to develop computational thinking skills systematically. Through support for digital circuit simulations, logic animation, and adaptive quizzes, students not only passively learn concepts but also actively engage in analysis, problem decomposition, algorithmic solution design, and evaluation. In addition, integrating media design with learning outcomes and curriculum assessments ensures that improving students' computational skills aligns with improving academic achievement, making this innovation potentially significant for the quality of learning. Based on this description, this study aims to evaluate the influence of the application of interactive mobile learning that is directly integrated into the learning process of Digital Systems courses. The evaluation focuses on two main aspects: improving computational thinking skills and learning achievement.

METHOD

The research subjects came from pre-formed classes, so complete randomisation was not possible. Therefore, the research design used was a Nonequivalent Control Group Pretest-Posttest design. The sample determination resulted in six classes, which were divided into experimental and control groups (Pramashela et al., 2023; Pratiwi & Santyasa, 2021). The class division is shown in Table 1.

Table 1. Research Design

No.	Group	Pre-test	Treatment	Post-test
1	Control Class	O_1	X_1	O_2
2	Experimental Class	O_3	X_3	O_4

The design of this study compared the effects of treatment between the experimental and control groups by measuring the variables studied before and after the treatment (Suliyanthini & Yulianur, 2023). Both groups were given initial tests to measure computational thinking skills and learning achievement before treatment. The experimental group consisted of 56 students drawn from Classes B, D, and E, who participated in learning activities using interactive mobile learning features. Meanwhile, the control group included 56 students from Classes A, C, and F who received direct instruction. The intervention was implemented over one lecture cycle, comprising six meetings.

The research instruments in this study consisted of two variables. First, a computational thinking test is developed to measure four indicators: problem decomposition, pattern recognition, abstraction, and algorithmization. Second, a learning achievement test that focuses on measuring students' cognitive abilities, including the levels of concept, analysis, understanding, and application in the Digital System course. The research instruments are shown in Table 2 and Table 3.

Table 2. Indicators of Computational Thinking

No.	Indicators of Computational Thinking	Explanation
1	Dekomposisi	Ability to break down complex problems into simpler parts
2	Pattern recognition	Ability to identify regularity or similarities in data and processes
3	Abstraksi	Ability to focus on relevant information while ignoring unimportant details
4	Algoritma	Ability to design systematic steps to solve problems

Table 3. Learning Achievement Instruments

No.	Learning Achievement Instruments	Competence
1	Describe the main differences between combination logic sets and sequential logic sets in digital systems design.	C2 - Understanding
2	Describe the central role of basic logic gates (AND, OR, NOT) and how they combine to form a simple digital circuit.	C2 - Understanding
3	Make an illustration and explain the working mechanism of shift registers in digital systems, including one example of its application.	C3 - Application

No.	Learning Achievement Instruments	Competence
4	Describe the stages of the process of converting analogue signals to digital signals in digital systems, and mention the role of ADC components.	C2 - Understanding
5	Arrange the steps of creating a counter and clock-based circuit that turns on the LEDs alternately at every 1-second interval.	C3 -Application
6	Analyse the differences in the communication characteristics of synchronous and asynchronous data in digital systems, and explain their effect on transmission performance.	C4 - Analyze
7	Explain the concept of interruption in a digital system that uses a microcontroller, then give an example of its use in an automated sensor-based system.	C4 - Analyze
8	Design a flowchart or process narrative of a digital system that activates an automatic fan based on temperature readings from sensors.	C6 - Create
9	Describe the procedure for connecting a 16x2 LCD module to a digital circuit and explain how the data is transmitted until it appears on the screen.	C3 - Application
10	Describe the steps of determining the type of logic circuit or processor that is appropriate for a digital control system, along with the technical reasons for the choice.	C5 - Evaluate

The computational thinking and learning achievement test instruments were subjected to validity and reliability testing to ensure their measurement adequacy. Content validity was evaluated using Aiken's V method through expert judgment by three specialists, yielding coefficients of 0.88 for the computational thinking instrument and 0.92 for the learning achievement instrument (Muskhir et al., 2025). Internal consistency reliability was assessed using Cronbach's Alpha, which produced a coefficient of 0.79, indicating acceptable reliability. Only instruments that satisfied the validity and reliability criteria were used for data collection.

The collected data were analysed using multivariate analysis of covariance, independent T-tests, and N-gain analysis to examine differences in learning outcomes between groups (Ekayana et al., 2025). These three formulas were used to provide more comprehensive results from the implementation of the learning methods applied to each class (Tafakur et al., 2023). These three analysis techniques were used to draw more convincing conclusions about whether differences resulted from the implementation of the learning methods (Syahri et al., 2021). Prior to hypothesis testing, prerequisite analyses were conducted to determine the suitability of parametric statistical techniques. These analyses included tests of normality and homogeneity of variance.

RESULTS AND DISCUSSION

Results

The research process involved six classes, divided proportionally into two groups: three in the experimental group and three in the control group. The learning process was carried out six times according to the predetermined treatment plan. Before the learning implementation, all participants were given a pretest that had undergone validity and reliability testing. The descriptive results of each research variable are shown in Table 4.

Table 4. Descriptive Summary of Computational Thinking Results and Learning Achievement

Model	Variabel	Mean	Standard deviation	Minimum Score	Maximum Score	Range
K-1 (Classes using *interactive mobile learning*)	Computational Thinking	60,68	21,490	22	98	76
	Learning Achievement	59,77	24,508	20	100	80
K-2 (Classes using conventional methods	Computational Thinking	54,32	16,402	20	84	64
	Learning Achievement	53,21	20,980	20	100	80

Based on the results of the descriptive analysis in Table 4, the average value of computational thinking in the experimental class (K-1) was 60.68, while the control class (K-2) reached only 54.32. In terms of learning achievement, K-1 achieved an average of 59.77, higher than K-2, which achieved 53.21. This average difference shows that the application of an interactive mobile learning model has a greater impact than conventional learning methods. The descriptive results provide an initial analysis indicating that the classes provided by Interactive Mobile Learning during the learning process yield superior results compared to those from the direct instructional method.

The prerequisite tests were conducted before hypothesis testing and included normality and homogeneity analyses. These tests were performed to determine the suitability of the data for MANCOVA analysis. The normality test evaluated whether the students' pretest and posttest scores were normally distributed, while the homogeneity test assessed whether the variances between the experimental and control groups were equal, ensuring valid comparisons. The results showed that the data satisfied the assumptions of normality and homogeneity. A detailed summary of these findings is presented in Table 5, Table 6, and Table 7.

Table 5. Results of the Prerequisite Test for Data Normality

Variabel	Learning	Kolmogorov-Smirnova Minimum Score		
		Statistic	**df**	**Sig.**
Computational Thinking	Classes using interactive mobile learning	0.95	112	0.241
	Classes using conventional methods	0.75	112	0.162
Learning Achievement	Classes using interactive mobile learning	0.68	112	0.127
	Classes using conventional methods	0.72	112	0.133

Table 6. Results of the Prerequisite Test for Homogeneity of Variance

Levene	df_1	df_2	**Sig.**
Computational Thinking	1	110	0.153
Learning Achievement	1	110	0.280

Table 7. Results of the Prerequisite Test for Variance between Groups

Box's M	**F**	**Sig.**
11.765	1.854	0.098

The data were tested for normality using the Kolmogorov-Smirnov test, as shown in Table 5. The test results showed that the computational thinking variable in the experimental group with interactive mobile learning had a significance value of 0.241. In contrast, the control group with conventional methods obtained a value of 0.162. Meanwhile, the learning achievement variable in the experimental group showed a significance value of 0.127, and in the control group, 0.133. All of these values are above the significance level of $\alpha = 0.05$, so it can be concluded that the distributions of pretest and posttest data for both variables are in the standard distribution category. Furthermore, the variance homogeneity test was performed to assess the uniformity of data dispersion across groups. Based on the homogeneity results shown in Table 6, the significance values for the computational thinking variable and greater learning achievement were 0.153 and 0.280, respectively, which are not significant at the 0.05 level, indicating no significant difference in variance between the experimental and control groups.

Since the study involves more than one variable, the prerequisite analysis is conducted not only on each variable separately but also on combinations of variables. Therefore, variance homogeneity testing was conducted jointly across groups on the variables of computational thinking and digital system learning achievement. This test is carried out using Box's Test of Equality of Covariance Matrices, which evaluates the similarity of the variance-covariance matrices across the groups being compared. The results of Box's M analysis in Table 7 show a significance value of 0.098, which is greater than the significance level of $\alpha = 0.05$. This indicates that the variance-covariance matrix across groups is not different, so the homogeneity assumption of covariance is met.

Table 8. Results of the Multivariate Analysis of Covariance Test are Simultaneously

Effect	F Coefficient	Sig.
Intercept	5966.746	0.000
	5966.746	0.000
	5966.746	0.000
	5966.746	0.000
Learning Methods	34.797	0.000
	34.797	0.000
	34.797	0.000
	34.797	0.000

Based on the results of the simultaneous statistical analysis in Table 8, the F coefficient was 34.797, with a significance value (Sig.) = 0.000 (< 0.05). These results show that learning method variables significantly influence the dependent variables simultaneously. In addition, the Intercept value also shows an F coefficient of 5966.746 with a significance of 0.000. This emphasises that interactive media-based learning methods can significantly influence variables in computational thinking and learning achievement.

Table 9. Results of the multivariate analysis of covariance

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Learning Methods	Computational Thinking	3774.188	1	3774.188	45.348	.000
	Learning Achievement	3165.178	1	3165.178	17.973	.000
Pretest Computational Thinking	Computational Thinking	87.524	1	87.524	1.052	.307
	Learning Achievement	6.375	1	6.375	.036	.849
Pretest Learning Achievement	Computational Thinking	.054	1	.054	.001	.980
	Learning Achievement	.219	1	.219	.001	.972
Error	Computational Thinking	8905.403	107	83.228		
	Learning Achievement	18843.840	107	176.111		
Total	Computational Thinking	624872.000	112			
	Learning Achievement	674972.000	112			
Corrected Total	Computational Thinking	13925.714	111			
	Learning Achievement	22271.107	111			

The multivariate analysis of covariance results presented in Table 9, describe the effect of the independent variable on the dependent variables after controlling for the covariates. The learning method showed a statistically significant effect on computational thinking skills, F(1, 107) = 45.348, p < .001, and on learning achievement, F(1, 107) = 17.973, p < .001. These findings indicate that differences in instructional methods were associated with differences in students' computational thinking and learning achievement. In contrast, the covariate pretest of computational thinking did not show a significant effect on computational thinking skills, F(1, 107) = 1.052, p = .307, or on learning achievement, F(1, 107) = 0.036, p = .849. Similarly, the covariate pretest of learning achievement did not significantly affect computational thinking skills, F(1, 107) = 0.001, p = .980, or learning achievement, F(1, 107) = 0.001, p = .972. These results suggest that students' initial scores did not significantly influence posttest outcomes after controlling for the treatment. The Tests of Between-Subjects Effects further support that the observed differences in outcomes were primarily associated with the learning method rather than baseline ability.

Table 10. Independent Samples T-Test Test Results

	T-test for Equality of Means					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Computational Thinking	6.474	110	.000	11.714	8.129	15.300
	6.474	99.916	.000	11.714	8.124	15.304
Learning Achievement	4.392	110	.000	10.893	5.977	15.808
	4.392	109.116	.000	10.893	5.977	15.809

The Independent Samples t-test is performed to ensure that the difference in different learning outcomes is statistically significant. This analysis aimed to evaluate the extent to which interventions were given to both groups. A summary of the test results is presented in Table 10. The Independent Samples t-test showed a statistically significant difference between the experimental and control groups. The computational thinking variable produced a t-value of 6.474 with 110 degrees of freedom (df) and a significance value (p) of 0.000 (< 0.05). In contrast, the learning achievement variable obtained a t-value of 4.392 with a df of 110 and a significance value (p) of 0.000 (< 0.05). These results confirm that the learning intervention applied to the experimental group had a significant effect compared to the direct instruction method used in the control group.

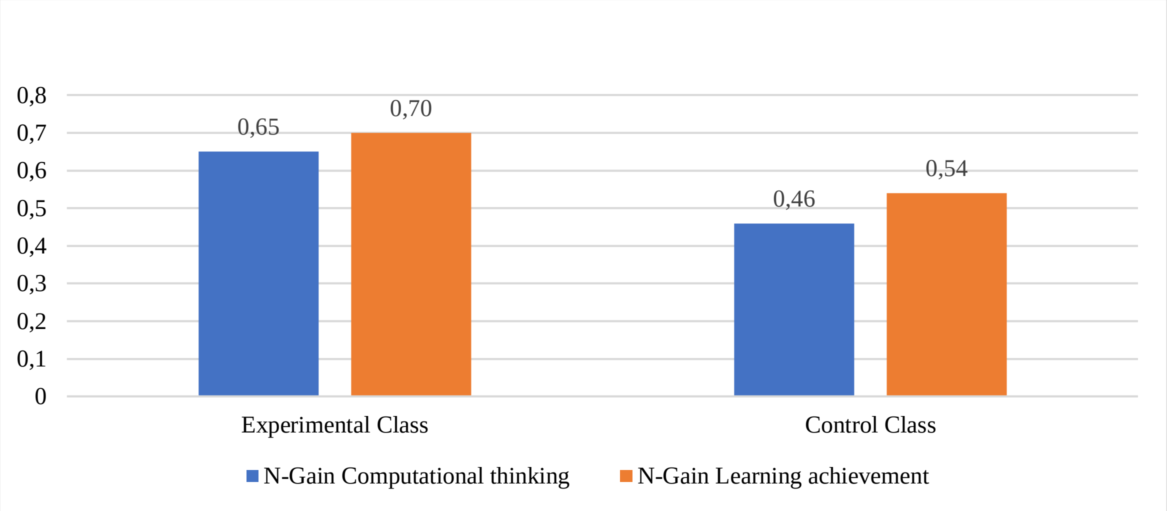

Figure 1. N-gain Comparison Results for each Class and Variable

Based on the N-Gain analysis shown in Figure 1, the increase in computational thinking ability and learning achievement was greater in the experimental class than in the control class. In the computational thinking variable, the initial average value of the experimental class (41.64) increased to 79.71 in the final measurement, resulting in an N-Gain of 0.65, which was classified as a moderate to high increase. In contrast, the control class increased from 40.64 to 68, with an N-Gain of 0.46, placing it in the moderate improvement category. The learning achievement variable for the experimental class showed a significant increase from an initial average score of 37.75 to 81.78 at the final measurement, with an N-Gain of 0.70, indicating significant improvement. Meanwhile, the control class only increased from 35.53 to 70.89, resulting in an N-Gain of 0.54, which is classified as a medium category. Based on the results of the N-Gain analysis, the intervention, which used interactive learning media in the experimental class, was shown to make a more significant contribution to improving computational thinking skills and learning achievement than conventional learning methods in the control class.

Discussion

The findings of this study show that the application of interactive learning media has a significant positive impact on improving computational thinking skills and student learning achievement when compared to conventional learning methods. This increase is consistent with the results of the Independent Samples t-test and the N-Gain, which show that interactive media-based interventions can strengthen computational thinking skills and learning achievement. These results can be explained through the theoretical framework of learning media, which states that interactive media allows multimodal learning, where the integration of text, visuals, animation, and interactivity can facilitate dual coding and reduce excessive cognitive load (Criollo-C et al., 2024; Perez-Poch et al., 2021; Sudiarti et al., 2023). This approach aligns with constructivist learning principles, in which learners actively build knowledge through interaction with content and contextually designed learning environments (Budyastuti & Fauziati, 2021; Masgumelar & Mustafa, 2021; Subiki et al., 2023).

Several recent studies align with the present findings and reinforce the role of interactive mobile learning in enhancing higher-order thinking and academic performance. Prior research has demonstrated that interactive media in STEM education can significantly improve students' problem-solving and advanced thinking skills compared with lecture-based instruction (Zhuang et al., 2021). Mobile-based and project-oriented learning environments have also been shown to increase students' motivation, self-efficacy, and academic achievement in engineering contexts (Ariza, 2023). Evidence indicates that mobile learning interventions effectively support the development of students' critical thinking skills across educational levels. In a related study, Rahman et al., (2025) reported that mobile-based interactive media significantly improved learning outcomes and student engagement in digital learning environments (Rahman et al., 2025). The present study extends these findings by providing empirical evidence within the specific context of Digital Systems courses, demonstrating that syllabus-integrated interactive media can simultaneously enhance computational thinking skills and learning achievement. This consistency with prior research suggests that interactive mobile learning contributes to more engaging and cognitively supportive learning environments that foster deeper conceptual understanding.

The integration of interactive learning media into digital system lectures can be an effective strategy to improve the quality of learning in computational thinking and learning achievement. This finding provides a logical consequence for educators: the need to design teaching materials that are not only oriented to the delivery of information but also encourage active student interaction and deep reflection (Pratama et al., 2023). In addition, learning media developers are expected to utilise the principles of multimedia learning and user experience so that the media produced is not only visually appealing but also effective in facilitating meaningful learning (Zulfa, 2025). Although the research has implications for improving computational thinking skills and learning achievement, it also has limitations that need to be considered. First, the study covered only one course and involved a limited sample of two classes, so generalising the results to a broader learning context required further research. Second, the relatively short duration of the intervention did not fully allow for evaluating the long-term impact of interactive media on knowledge retention. Further research should explore the implementation of interactive media across courses with varying topic coverage and levels of complexity, as well as with extended intervention periods, to assess the sustainability of their impact on knowledge and skill retention. Additional measures of variables such as learning motivation, collaborative skills, and digital literacy should also be considered to obtain a more comprehensive picture of the effectiveness of interactive media.

CONCLUSION

Based on the findings, it can be concluded that the implementation of interactive mobile learning media is efficacious in improving students' computational thinking skills and learning achievement in Digital Systems courses. Students who learned through mobile-based interactive media achieved superior outcomes compared with those receiving conventional instruction, indicating that mobile interactive learning is a practical instructional approach for enhancing cognitive skills and academic performance. These findings imply that integrating interactive mobile media into higher education teaching practices can support more student-centred, engaging, and adaptive learning environments. Therefore, lecturers are encouraged to incorporate interactive mobile learning into their instructional strategies to foster active learning and strengthen students' higher-order thinking skills. Educational institutions are advised to support this implementation through adequate infrastructure, professional development, and institutional policies that promote digital learning innovation. Future research should examine longer-term implementation across diverse courses and levels of content complexity to evaluate the sustainability of learning gains and explore the integration of interactive mobile learning with other instructional approaches, such as project- and problem-based learning.

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