

ENHANCING COGNITIVE ACHIEVEMENT THROUGH GAMI- FIED MOBILE LEARNING-SUPPORT- ED PROBLEM-BASED LEARNING IN INFORMATICS EDUCATION

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ABSTRACT

Aim. This study examines the effectiveness of integrating gamified mobile learning with Problem-Based Learning (PBL) in improving cognitive achievement in secondary Informatics education. It explores students' learning progress across different cognitive levels.

Methods. A quasi-experimental pretest–posttest design with two comparison groups was employed. The participants were 72 tenth-grade Informatics students. The experimental group learned through PBL supported by a gamified mobile learning platform, whereas the control group received conventional instruction. Learning outcomes were analysed using descriptive and inferential statistics.

Results. The experimental group achieved significantly greater learning gains than the control group, with higher normalised gain scores and significantly better posttest performance ($t = 3.880$, $p < .001$). The large effect size ($d = 0.91$) indicates a substantial difference between the groups. Improvements were also observed across all assessed cognitive levels (C1–C5).

Conclusions. Integrating gamified mobile learning with Problem-Based Learning was associated with improved cognitive achievement in Informatics education, including gains across both lower- and higher-order cognitive levels.

Research Restrictions. The study was conducted in a single secondary school and focused only on Algorithms and Programming, limiting the generalisability of the findings.

Practical Application. Teachers can integrate gamified mobile learning into PBL to promote active engagement, independent learning, and improved academic performance in Informatics classrooms.

Cognitive Value. This study provides empirical evidence that combining gamification, mobile learning, and PBL enhances cognitive development across multiple cognitive levels in technology-enhanced learning.

Keywords: gamified mobile learning, problem-based learning, informatics education, cognitive achievement, educational technology, quasi-experimental study

INTRODUCTION

The rapid advancement of digital technology has transformed educational practices and raised expectations for students to develop higher-order thinking skills, problem-solving abilities, and independent learning competencies (Akour & Alenezi, 2022). As digital technologies continue to reshape society, education is expected not only to provide subject knowledge but also to equip learners with the competencies required to adapt to increasingly technology-driven environments. Within this context, Informatics education has become an essential component of secondary education because it develops computational thinking, algorithmic reasoning, and digital problem-solving skills that are fundamental for academic success and future careers (Trishaank et al., 2025).

Despite its growing importance, learning Informatics remains challenging for many secondary school students, particularly in topics related to algorithms and programming (Humble, 2023). These topics often involve abstract concepts that require logical reasoning, systematic thinking, and the ability to translate problems into computational solutions. However, conventional classroom instruction frequently emphasises the transmission of knowledge rather than active knowledge construction, limiting opportunities for students to engage deeply with learning content and apply concepts in authentic contexts (Ho, 2024). As a result, many students experience difficulties in developing the higher-order cognitive skills required to solve computational problems effectively.

At the same time, the rapid development of educational technology has created new opportunities to enhance teaching and learning practices. Digital learning environments can provide greater flexibility, richer learning resources, immediate feedback, and continuous access to instructional materials beyond the classroom (Diputra, Husin, Karimi, et al., 2025; Fadillah et al., 2026). When supported by appropriate pedagogical strategies, technology has the potential to create more engaging learning experiences while promoting meaningful knowledge construction and cognitive development. Nevertheless, technology alone cannot guarantee improved learning outcomes. Its educational value depends largely on how it is integrated into well-designed instructional approaches that encourage active participation, inquiry, and problem-solving (Fadhilah & Husin, 2026; Husin et al., 2025).

Against this background, the present study investigates the effectiveness of integrating gamified mobile learning with Problem-Based Learning (PBL) in secondary Informatics education. Rather than examining educational technology as an isolated instructional tool, this study explores its role within a structured pedagogical framework designed to support students' cognitive development. Specifically, the study evaluates whether this integrated instructional approach can improve students' cognitive achievement across multiple cognitive levels in Algorithms and Programming, thereby contributing to a better understanding of technology-enhanced learning in secondary Informatics education.

THEORETICAL BACKGROUND

Problem-Based Learning

Problem-Based Learning (PBL) has been widely recognised as an effective student-centred instructional approach for promoting active learning, critical thinking, and problem-solving skills across diverse educational contexts (Smith et al., 2022). Unlike conventional teacher-centred instruction, PBL places authentic problems at the centre of the learning process, encouraging students to investigate real-world situations, collaborate with peers, and construct knowledge through inquiry and reflection (Gillies, 2023). Through this process, students assume greater responsibility for their own learning while developing both conceptual understanding and transferable problem-solving competencies. A growing body of research has demonstrated the positive educational impact of PBL. Previous studies have reported that PBL enhances students' critical thinking, learning motivation, academic achievement, and collaborative skills in science and technology-related disciplines (Bi et al., 2024). By engaging learners in authentic and meaningful learning activities, PBL encourages them to connect theoretical knowledge with practical applications, thereby promoting deeper understanding rather than surface memorisation.

Within Informatics education, PBL is particularly relevant because computational problems require students to analyse complex situations, develop logical solutions,

and evaluate alternative approaches (Husin et al., 2024; Son & Kim, 2025). Learning topics such as algorithms and programming involves more than acquiring factual knowledge; students must also apply concepts systematically to solve computational problems. Consequently, instructional approaches that emphasise inquiry, collaboration, and authentic problem solving are considered especially appropriate for developing the cognitive competencies required in Informatics learning. Despite its educational advantages, the successful implementation of PBL depends on adequate instructional support throughout the learning process. Students may encounter difficulties when investigating complex problems, organising learning activities, or maintaining motivation over extended periods without sufficient guidance and learning resources (Kristianto & Gandajaya, 2023). These challenges suggest that PBL may be more effective when complemented by educational technologies that provide continuous learning support, accessible instructional resources, and opportunities for independent learning.

Mobile Learning

Mobile learning has become an increasingly important approach for supporting flexible and accessible learning in contemporary education. The widespread availability of smartphones enables students to access learning resources at any time and from any location, extending learning opportunities beyond the traditional classroom (Houghton, 2023). This flexibility allows learners to review instructional materials, complete learning activities, and engage with educational content at their own pace, thereby supporting more personalised learning experiences. Mobile learning environments provide several educational advantages. Through mobile applications, students can access instructional materials, multimedia resources, quizzes, and immediate feedback, all of which contribute to continuous engagement with learning content (Ebbini, 2023). Previous studies have reported that mobile learning positively influences academic achievement, learner autonomy, learning flexibility, and self-directed learning by enabling students to regulate their own learning processes more effectively (Fujii, 2024).

Although mobile learning offers considerable educational potential, many existing implementations primarily function as platforms for delivering instructional content rather than facilitating active knowledge construction (Okai-Ugbaje et al., 2022). In many cases, students access digital materials without engaging in meaningful inquiry, collaboration, or higher-order thinking activities. Consequently, the educational benefits of mobile learning depend not only on the technology itself but also on the pedagogical approaches through which it is implemented. For this reason, recent educational research has increasingly emphasised integrating mobile learning with student-centred instructional models that encourage active participation and collaborative problem-solving. Rather than replacing classroom instruction, mobile technologies can complement pedagogical approaches by providing continuous access to learning resources,

supporting self-paced learning, and facilitating sustained engagement throughout the learning process. Such characteristics make mobile learning particularly suitable for supporting instructional approaches such as Problem-Based Learning, where students require ongoing access to information, learning materials, and feedback while investigating authentic problems.

Gamification in Education

Gamification has emerged as a promising strategy for increasing student engagement and motivation by incorporating game-inspired elements into educational environments. Rather than transforming learning into a game, gamification applies selected game design principles, such as challenges, points, badges, progress indicators, and immediate feedback, to support learning activities and encourage sustained participation (Kaya & Ercag, 2023). When implemented appropriately, these elements can create more interactive learning experiences that promote persistence, active participation, and continuous engagement throughout the learning process. Numerous studies have reported the positive effects of gamification on educational outcomes. Gamified learning environments have been shown to improve students' motivation, classroom participation, academic performance, and learning satisfaction across various disciplines (García-López et al., 2023). Immediate feedback, clearly defined learning goals, and visible indicators of progress encourage students to monitor their own performance and remain actively involved in learning activities. These characteristics are particularly valuable in technology-based learning environments, where maintaining learner engagement is often a significant challenge.

Despite these advantages, the educational effectiveness of gamification depends largely on its pedagogical implementation. Many educational applications incorporate only superficial game elements, such as points, badges, and leaderboards, without establishing meaningful connections between motivational features and learning objectives (Saleem et al., 2022). Although such approaches may increase short-term engagement, they do not necessarily promote conceptual understanding or higher-order cognitive development. Consequently, researchers have increasingly argued that gamification should be integrated into sound instructional designs that encourage inquiry, collaboration, and active knowledge construction rather than functioning merely as an external motivational tool.

Integrating Gamified Mobile Learning with Problem-Based Learning

Recent developments in educational technology suggest that greater learning benefits may be achieved by integrating complementary instructional approaches rather than implementing each approach independently (Diputra, Husin, Fadhillah, et

al., 2025). Within such an integrated learning environment, Problem-Based Learning provides authentic learning experiences that encourage inquiry, collaboration, and problem-solving (Husin et al., 2025). In contrast, mobile learning extends access to instructional resources beyond the classroom and supports flexible, self-paced learning. Gamification further complements these approaches by enhancing motivation, sustaining engagement, and encouraging students to participate actively throughout the learning process. Together, these components create a technology-enhanced learning environment that simultaneously supports cognitive engagement, learner autonomy, and meaningful knowledge construction.

The integration of these approaches is particularly relevant to Informatics education, where students are expected not only to acquire conceptual knowledge but also to apply, analyse, and evaluate computational solutions in authentic contexts. Learning topics such as algorithms and programming requires students to engage in systematic reasoning, identify appropriate solution strategies, and reflect on the effectiveness of alternative approaches. By combining authentic problem-solving activities with continuous access to learning resources and motivational learning experiences, gamified mobile learning-supported Problem-Based Learning has the potential to strengthen both conceptual understanding and higher-order cognitive skills. Although substantial evidence supports the educational value of Problem-Based Learning, mobile learning, and gamification individually, empirical studies integrating all three approaches within secondary-level Informatics education remain relatively limited. Existing research has predominantly examined these instructional approaches separately or through combinations of only two components, such as gamification with mobile learning or gamification with Problem-Based Learning, leaving the educational effects of integrating all three approaches insufficiently explored (Boom-Cárcamo et al., 2024). Moreover, previous studies have largely focused on learning motivation, engagement, or overall academic achievement rather than examining how such instructional integration influences students' performance across different cognitive levels (Jaramillo-Mediavilla et al., 2024).

This limitation is particularly important because success in Informatics education requires more than knowledge acquisition. Students are expected to apply computational concepts, analyse programming problems, evaluate alternative solutions, and demonstrate higher-order thinking throughout the problem-solving process (Fadhilah & Husin, 2023; Zhang et al., 2024). Nevertheless, relatively few studies have investigated whether integrating gamified mobile learning within a Problem-Based Learning framework can enhance students' cognitive achievement across multiple cognitive levels in secondary Informatics education (Swacha & Szydłowska, 2023). To address this gap, the present study examines the effectiveness of gamified mobile learning-supported Problem-Based Learning in improving students' cognitive achievement across different cognitive levels in Algorithms and Programming. The findings are expected to contribute to a broader understanding of how pedagogically integrated, technology-enhanced learning environments can support cognitive development in secondary Informatics education.

METHODOLOGY

Research Questions

This study was conducted to evaluate the effectiveness of integrating gamified mobile learning with Problem-Based Learning (PBL) in secondary Informatics education. Specifically, the study addressed the following research questions:

- *RQ1*. To what extent does gamified mobile learning integrated with Problem-Based Learning improve students' learning outcomes in Informatics education?
- *RQ2*. How does the implementation of gamified mobile learning within a Problem-Based Learning environment influence students' cognitive achievement across different cognitive levels?

Research Design

To examine the impact of the proposed instructional approach, the study adopted a quasi-experimental design involving pretest and posttest measures in experimental and control groups. This approach enabled comparisons of learning achievement while considering students' baseline knowledge. Two intact classes participated in the study, with one class assigned to the intervention condition and the other serving as a comparison group. Students in the intervention group learned through PBL integrated with a gamified mobile learning application, whereas those in the comparison group followed conventional learning activities. The research design and measurement structure are presented in Appendix A (Table A1).

Participants and Context

Seventy-two Grade 10 students taking Informatics courses at a senior high school in western Indonesia participated in the study. The sample was split evenly between an experimental group ($n = 36$) and a control group ($n = 36$). The two intact classes were selected from the same grade level and studied the same Algorithms and Programming content within the same school context. An independent-samples t -test indicated no statistically significant difference in pretest achievement between the experimental and control groups ($p = .112$), indicating comparable baseline achievement. The study focused on Algorithms and Programming, a fundamental yet challenging area of secondary-level Informatics education. The intervention was implemented during regular classroom instruction under the supervision of the course teacher.

Learning Intervention

Students in the experimental group learned through a combination of Problem-Based Learning and a gamified mobile learning application developed specifically for secondary Informatics education. The instructional activities followed the core phases of PBL: problem orientation, learning organisation, investigation, solution presentation, and reflection (Husin et al., 2025). The mobile learning application was developed using a Research and Development (R&D) approach based on the 4D model, consisting of the define, design, develop, and disseminate stages. The developed media underwent expert evaluation of both the media and instructional material quality. The expert assessment indicated satisfactory validity, with Aiken's V values of 0.821 for media quality and 0.781 for instructional material quality.

The application provided learning materials, instructional videos, student worksheets, quizzes, and educational game activities. The game component included learning challenges integrated with the instructional content and provided opportunities for students to practice and evaluate their understanding. The application also provided immediate feedback to support students during learning activities. Thus, the gamified features were embedded within the instructional activities and used to complement the PBL process rather than function as separate entertainment activities. Students accessed the application using their personal smartphones during and outside classroom sessions. In contrast, students in the control group received conventional instruction. The teacher delivered lessons through lectures supported by PowerPoint presentations and printed worksheets. Learning activities primarily focused on content explanation and individual exercises without the use of gamified mobile learning resources. Both groups studied the same learning objectives and Algorithms and Programming content during the intervention period. Figure 1 presents selected interfaces of the gamified mobile learning application used in the experimental group.

Figure 1

Learning Activities Supported by the Gamified Mobile Learning Application



Source. Own research.

Instruments

Students' cognitive achievement was assessed using a researcher-developed multiple-choice test on Algorithms and Programming comprising 25 dichotomously scored items. The items covered five cognitive levels derived from Bloom's original taxonomy (Bloom, 1956) and its revised version (Anderson & Krathwohl, 2001): remembering (C1), understanding (C2), applying (C3), analysing (C4), and evaluating (C5), with five items allocated to each cognitive level. Each item was scored as 0 for an incorrect response and 1 for a correct response. Thus, the overall raw test score ranged from 0 to 25, while the raw score for each cognitive dimension ranged from 0 to 5. For reporting and interpretation, raw scores were converted to a 0–100 scale; therefore, both the overall achievement score and each cognitive-dimension score had a minimum of 0 and a maximum of 100. Because each cognitive dimension contained the same number of items, the five dimensions were equally represented and equally weighted in the overall achievement score.

Because all test items were dichotomously scored, internal consistency reliability was assessed using the Kuder–Richardson Formula 20 (KR-20). The overall test yielded a KR-20 coefficient of 0.83, while the coefficients for C1–C5 were 0.76, 0.81, 0.79, 0.86, and 0.83, respectively. These values indicate satisfactory internal consistency for the overall test and each cognitive dimension. The same instrument was administered as both the pretest and posttest to ensure comparability of students' cognitive achievement before and after the instructional intervention. In addition to the overall achievement score, students' performance was analysed according to the five cognitive levels of Bloom's revised taxonomy to examine changes across different dimensions of cognitive achievement.

Data Analysis

To examine the impact of the intervention, several statistical procedures were employed. Students' achievement patterns before and after instruction were first summarised descriptively. The magnitude of learning growth was then estimated using normalised gain scores and interpreted according to established N-Gain categories proposed by Richard R. Hake (1998). Finally, a comparison of achievement outcomes between the two groups was conducted through an independent-samples t-test. Before conducting the comparison, the dataset underwent assumption checks to verify an acceptable distribution pattern and comparable variability between groups. All obtained p-values were above .05, indicating that the assumptions were not violated. Statistical significance for hypothesis testing was determined at the 0.05 level. The practical importance of the treatment was examined using Cohen's d. Following established guidelines, values around 0.20 indicated a small effect, values near 0.50 reflected

a moderate effect, and values of at least 0.80 represented a large effect (Cohen, 1988). Furthermore, changes in students' achievement across the five cognitive levels were examined using paired-samples *t*-tests for each group. Effect sizes (Cohen's *d*) were also calculated to determine the magnitude of the observed changes.

RESULTS

Learning Outcome Improvement

The first stage of the analysis examined patterns of achievement in both groups before and after instruction. Descriptive summaries of the resulting scores are reported in Appendix A (Table A2). The descriptive results presented in Appendix A (Table A2) reveal positive achievement growth in both groups. Although students in each group obtained higher posttest scores than pretest scores, the increase was more pronounced in the experimental group. Mean scores rose from 45.25 to 78.89 in the experimental class and from 48.33 to 71.06 in the control class. Consistent with these results, the N-Gain values showed a higher level of improvement among students exposed to gamified mobile learning-supported PBL (0.60) than among those receiving conventional teaching (0.44). These findings indicate the added value of the intervention in promoting learning achievement.

Cognitive Achievement Across Different Levels

To investigate how the intervention influenced different dimensions of cognitive achievement, students' performance was analysed across the five cognitive levels of Bloom's taxonomy (Anderson & Krathwohl, 2001). Paired-samples *t*-tests were conducted separately for the experimental and control groups to examine changes between the pretest and posttest scores. The results for the experimental group are presented in Appendix A (Table A3), whereas the corresponding results for the control group are presented in Appendix A (Table A4). The paired-samples *t*-test results for the experimental group revealed statistically significant improvements across all five cognitive levels ($p < .05$). Large effect sizes were observed for every cognitive dimension (Cohen's $d = 0.95\text{--}1.44$), indicating substantial within-group improvements in students' cognitive achievement. The corresponding results for the control group also showed statistically significant improvements across all five cognitive levels, although the magnitude of the effects varied across dimensions (Appendix A, Table A4).

The paired-samples *t*-test results presented in Tables 3 and 4 indicate statistically significant improvements across all five cognitive levels in both groups. However, the magnitude of these improvements differed across cognitive dimensions. To deter-

mine whether the observed posttest advantage of the experimental group was consistent across the individual cognitive dimensions, additional independent-samples *t*-tests were conducted by comparing posttest scores between the experimental and control groups for each level of Bloom’s revised taxonomy (Anderson & Krathwohl, 2001). The results are presented in Appendix A (Table A5). The posttest comparison showed statistically significant differences between the experimental and control groups across all five cognitive levels. The largest between-group effect was observed for remembering (C1; Cohen’s *d* = 1.22), followed by understanding (C2; *d* = 0.94), applying (C3; *d* = 0.91), and analysing (C4; *d* = 0.82). The smallest, although still statistically significant, effect was observed for evaluating (C5; *d* = 0.60). These findings indicate that the posttest difference observed at the overall achievement level was not attributable to a single cognitive dimension. Rather, the experimental group demonstrated higher posttest achievement across all five cognitive levels, although the magnitude of the between-group differences varied across dimensions.

Assumption Testing

To determine whether parametric procedures could be applied, the researchers first examined the characteristics of the dataset. The obtained Shapiro–Wilk significance values (.073–.497) indicated that the score distributions did not deviate from normality. Furthermore, the Levene’s test result (*p* = .055) suggested that variability across groups remained comparable. Taken together, these findings confirmed that the assumptions underlying the planned statistical analyses were adequately satisfied.

Group Comparison and Effect Size

To evaluate whether the intervention produced different learning outcomes, the researchers applied an independent-samples *t*-test to the achievement data. The independent-samples *t*-test comparing posttest performance between the experimental and control groups is presented in Table 1.

Table 1
Independent-Samples *t*-Test and Effect Size Results

<i>t</i>	<i>df</i>	<i>p</i>	Cohen’s <i>d</i>
3.880	64.025	< .001	0.91

Note. The independent-samples *t*-test was conducted to compare posttest scores between the experimental and control groups. Cohen’s *d* represents the standardised effect size.
Source. Own research.

The independent-samples *t*-test indicated that posttest performance differed significantly between the two groups, $t(64.025) = 3.880, p < .001$. This result led to the rejection of the null hypothesis and suggests that students exposed to gamified mobile learning integrated with PBL achieved better learning outcomes than their peers who followed conventional instruction. To determine the magnitude of the intervention effect, Cohen's *d* was computed. The resulting value ($d = 0.91$) represents a large effect according to established interpretation criteria. Therefore, the intervention demonstrated not only statistical significance but also meaningful educational impact.

DISCUSSION

Effect of Gamified Mobile Learning-Supported PBL on Learning Achievement

Students exposed to the gamified, mobile-learning-supported PBL approach outperformed their peers who followed conventional instruction. In addition to achieving stronger posttest performance, the experimental group demonstrated a higher level of learning improvement based on N-Gain analysis. This pattern indicates that the intervention facilitated more effective knowledge development during the study period. Furthermore, the large effect size (Cohen's $d = 0.91$) suggests that the intervention produced substantial educational benefits beyond the level of statistical significance. These findings support the first research question and indicate that integrating gamified mobile learning into PBL can effectively enhance students' achievement in Informatics education. Several factors may explain this improvement. First, PBL actively engaged students in solving authentic problems rather than passively receiving information (Sukacké et al., 2022). Through problem investigation, discussion, and solution development, students were required to construct knowledge independently and apply concepts in meaningful contexts (Tan et al., 2023). Such learning experiences are consistent with constructivist learning theory, which emphasises active knowledge construction through interaction and problem solving (Piaget, 1970; Vygotsky, 1978). As a result, students developed a deeper understanding of algorithms and programming concepts than those who experienced conventional instruction.

Second, the mobile learning environment provided flexible access to learning resources and enabled students to continue learning beyond classroom sessions. Students could review instructional materials, watch learning videos, and complete learning activities at their own pace. This flexibility likely supported self-regulated learning and reduced dependency on teacher explanations. Previous studies have similarly reported that mobile learning environments can enhance learner autonomy and increase opportunities for continuous engagement with instructional content (Karakaya & Bozkurt, 2022). Third, incorporating gamification elements may have increased students'

motivation and persistence during learning activities. Features such as quizzes, challenges, progress indicators, and immediate feedback created a more interactive learning experience. Rather than viewing learning activities as routine classroom tasks, students were encouraged to participate and monitor their own progress actively. This finding aligns with previous research suggesting that gamification can improve engagement and academic performance when implemented within meaningful pedagogical frameworks (Almufarreh, 2026; Camacho-Sánchez et al., 2022; Husin, 2026).

An additional explanation for the observed improvement may be found in the complementary roles played by Problem-Based Learning, mobile learning, and gamification. Rather than functioning as separate instructional components, these approaches worked together to create a learning environment that simultaneously supported cognitive engagement and learner motivation (Chung & Pan, 2023; David & Weinstein, 2023). PBL provided meaningful problems that required active inquiry, mobile learning ensured continuous access to learning resources, and gamification encouraged sustained participation throughout the learning process (Lazaro & Duarte, 2023; Pedraja-Rejas et al., 2024). The combination of these elements may have reduced the cognitive barriers often encountered in learning algorithms and programming concepts (Schöbel et al., 2023). Consequently, students were able to spend more time interacting with learning materials and applying concepts to problem-solving tasks.

The findings also suggest that the effectiveness of the intervention was not solely attributable to technological features. Educational technologies frequently fail to improve learning outcomes when they are implemented without a clear pedagogical framework (Chugh et al., 2023; See et al., 2022). In the present study, technology served as a tool to reinforce instructional objectives rather than replace instructional processes. The gamified mobile learning application supported students during each phase of the PBL cycle, allowing technology to facilitate inquiry, collaboration, and reflection. This observation supports arguments in educational technology research that learning gains emerge when technology is integrated with sound pedagogical strategies rather than used merely for content delivery (Bizami et al., 2023).

Influence on Cognitive Achievement Across Different Levels

The second research question focused on how gamified mobile learning-supported PBL influenced students' achievement across different cognitive levels. The results revealed improvements at all levels of Bloom's taxonomy, including remembering (C1), understanding (C2), applying (C3), analysing (C4), and evaluating (C5). Although the largest gains were observed at lower cognitive levels, meaningful improvements were also evident in higher-order cognitive processes. These findings indicate that the intervention supported comprehensive cognitive development rather than merely improving factual knowledge. The substantial improvement in remember-

ing and understanding can be attributed to students' frequent exposure to instructional materials through the mobile learning application. The availability of videos, learning resources, and repeated practice opportunities likely strengthened knowledge retention and conceptual comprehension (Förster et al., 2022). Immediate feedback provided through quizzes may also have helped students identify misconceptions and reinforce correct understanding (Wong et al., 2025).

More importantly, improvements at the applying, analysing, and evaluating levels suggest that students developed higher-order thinking skills during the intervention. The problem-solving activities embedded within the PBL process required students to apply programming concepts to authentic situations, analyse alternative solutions, and evaluate the effectiveness of their decisions (Fitrah et al., 2025; Yang et al., 2023). These learning experiences encouraged deeper cognitive processing than conventional instructional approaches that primarily emphasise content delivery (Ssemugenyi, 2023). Consequently, students were not only able to recall information but also to use and critically examine Informatics concepts. This finding is particularly important in Informatics education because computational thinking and algorithmic problem-solving require students to operate beyond memorisation (Li et al., 2023). The ability to analyse problems, design solutions, and evaluate outcomes is an essential competency for learning programming and computational reasoning (Wu et al., 2025). Therefore, the observed improvements across cognitive levels suggest that integrating gamified mobile learning with PBL can support the development of fundamental skills in Informatics learning.

The pattern of improvement across cognitive levels also provides valuable insight into how students learn Informatics concepts. The larger gains observed at the remembering and understanding levels indicate that students first strengthened their conceptual foundations before demonstrating higher-order cognitive performance. This progression is consistent with the revised Bloom's taxonomy, in which higher-order cognitive processes build upon foundational forms of knowledge and understanding (Anderson & Krathwohl, 2001). Similar patterns have also been reported in recent educational applications of Bloom's taxonomy (Ravand et al., 2025; Ray et al., 2025). Therefore, the improvements at the analysing and evaluating levels may have been facilitated by students' stronger understanding of algorithms and programming concepts acquired during the intervention.

Another noteworthy finding is that meaningful gains were observed even at the evaluation level, which is generally considered one of the most demanding cognitive processes in secondary education. Evaluation tasks require students to assess the quality of solutions, compare alternative approaches, and justify decisions using established criteria (Hsiao et al., 2023). Such skills are closely associated with computational thinking and programming practice, where multiple solution pathways are often possible. The improvement observed at this level suggests that the integration of gamified mobile learning and PBL may contribute to the development of reflective and critical thinking abilities that are essential for Informatics learning.

Furthermore, the results indicate that technology-enhanced learning environments can support not only knowledge acquisition but also cognitive development. While some technology-based interventions primarily improve engagement or motivation, the present findings suggest broader educational benefits. Students demonstrated measurable progress across multiple cognitive dimensions, indicating that the intervention contributed to deeper learning outcomes. This observation strengthens the argument that educational technologies should be evaluated not only in terms of usability or satisfaction but also in relation to their capacity to promote meaningful cognitive growth (Vlachogianni & Tselios, 2022).

Implications for Informatics Education

The findings have practical implications for secondary Informatics education by suggesting that teachers can integrate gamified mobile learning with Problem-Based Learning (PBL) to support inquiry, problem-solving, active participation, and continuous engagement with learning materials. Rather than using mobile technology solely for content delivery or gamification merely as a motivational mechanism, educators can align these features with structured pedagogical activities so that learning resources, practice opportunities, feedback, and game-based challenges support meaningful learning objectives. The approach may also provide greater flexibility by allowing students to access learning resources beyond scheduled classroom sessions, which can help address time constraints when implementing problem-solving activities. From a curriculum perspective, the findings suggest that structured mobile learning and problem-based activities may complement Informatics curricula that emphasize computational thinking, problem solving, and digital literacy. At the research level, the study contributes evidence on the combined use of PBL, mobile learning, and gamification in secondary Informatics education. It highlights the value of examining achievement across multiple cognitive levels. Future research should examine the approach across more diverse educational contexts and investigate longer-term effects and additional outcomes, such as computational thinking, learning motivation, self-regulation, and problem-solving ability.

Limitations of the Study

This study has several limitations. First, the sample was drawn from a single senior high school, which may limit the generalisability of the findings. Second, the intervention focused exclusively on Algorithms and Programming topics within Informatics education. Third, the study examined short-term learning outcomes and did not investigate long-term knowledge retention. Fourth, the cognitive achievement test was researcher-developed and, although its internal consistency was established

using KR-20, formal expert validation and item-level analysis were not conducted. This measurement limitation should be considered when interpreting the findings. Future studies should involve larger and more diverse samples, explore additional Informatics topics, incorporate more comprehensive instrument validation procedures, and examine the sustainability of learning gains over extended periods.

CONCLUSION

This study evaluated the effectiveness of integrating gamified mobile learning with Problem-Based Learning (PBL) in supporting students' cognitive achievement in secondary Informatics education. The findings showed that students in the intervention group achieved higher posttest scores and greater learning gains than those in the conventional instruction group, with a large overall effect size. At the same time, improvements were also observed across all five assessed cognitive levels, from remembering and understanding to applying, analysing, and evaluating. These results suggest that integrating gamified mobile learning within a structured PBL framework can support both conceptual learning and higher-order cognitive development by providing accessible learning resources, practice opportunities, immediate feedback, and sustained engagement throughout the problem-solving process. The study therefore contributes to research on technology-enhanced Informatics education by demonstrating improvements not only in overall achievement but also across multiple cognitive dimensions. Nevertheless, the findings should be interpreted in light of the single-school sample, the focus on Algorithms and Programming, the short-term assessment of learning outcomes, and the limitations of the researcher-developed cognitive achievement test. Future research should examine the approach across more diverse educational contexts and over longer periods, while also considering broader outcomes such as computational thinking, learning motivation, self-regulation, problem-solving ability, and technology acceptance.

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APPENDIX

Table A1*Research Design*

Group	Pretest	Treatment	Posttest
Experimental	O ₁	X	O ₂
Control	O ₃	–	O ₄

Note. The symbols O1 and O3 denote measurements collected before the instructional treatment in the experimental and control groups, respectively, while O2 and O4 denote measurements collected after the intervention. The treatment itself, labelled X, consisted of a Problem-Based Learning approach enhanced through a gamified mobile learning application.

Source. Own research.

Table A2*Descriptive Statistics for Learning Achievement*

Group	Test	N	Mean	SD	N-Gain
Experimental	Pretest	36	45.25	10.77	0.60
	Posttest	36	78.89	6.80	
Control	Pretest	36	48.33	7.79	0.44
	Posttest	36	71.06	8.96	

Note. Mean represents the average achievement score, and SD represents the standard deviation. N-Gain represents the normalised gain calculated from the pretest and post-test scores for each group.

Source. Own research.

Table A3*Changes in Cognitive Achievement Across Different Cognitive Levels in the Experimental Group*

Cognitive Level	Pretest	Posttest	Gain	t	p	Cohen's d
C1 (Remembering)	52.65	86.11	33.46	8.62	< .001	1.44
C2 (Understanding)	47.22	80.56	33.34	7.41	.005	1.24
C3 (Applying)	44.44	77.78	33.34	7.96	.012	1.33
C4 (Analysing)	38.89	75	36.11	6.84	< .001	1.14
C5 (Evaluating)	43.06	75	31.94	5.71	< .001	0.95

Note. Pretest and posttest values represent scores converted to a 0–100 scale. Gain represents the difference between posttest and pretest scores. The *t* and *p* values are from paired-samples *t*-tests comparing pretest and posttest scores within the experimental group. Cohen's *d* represents the effect size of the pretest–posttest change.

Source. Own research.

Table A4*Changes in Cognitive Achievement Across Different Cognitive Levels in the Control Group*

Cognitive Level	Pretest	Posttest	Gain	t	p	Cohen's d
C1 (Remembering)	55.56	75.09	19.53	5.28	.021	0.88
C2 (Understanding)	50	73	23	4.86	< .001	0.81
C3 (Applying)	47.22	70	22.78	4.95	< .001	0.83
C4 (Analysing)	44.44	67.78	23.34	3.92	.017	0.65
C5 (Evaluating)	44.44	69.44	25	3.41	.002	0.57

Note. Pretest and posttest scores are reported on a 0–100 scale. Gain represents the difference between the posttest and pretest scores. The *t* and *p* values are from paired-samples *t*-tests comparing pretest and posttest scores within the control group. Cohen's *d* represents the effect size of the pretest–posttest difference.

Source. Own research.

Table A5*Posttest Comparison Between Experimental and Control Groups Across Cognitive Levels*

Cognitive Level	Experimental Mean	Control Mean	t	p	Cohen's d
C1 (Remembering)	86.11	75.09	5.163	< .001	1.22
C2 (Understanding)	80.56	73	4.001	< .001	0.94
C3 (Applying)	77.78	70	3.877	< .001	0.91
C4 (Analysing)	75	67.78	3.499	< .001	0.82
C5 (Evaluating)	75	69.44	2.549	0.013	0.66

Note. The independent-samples *t*-test compares posttest scores between the experimental and control groups for each cognitive level.

Source. Own research.