Exploring the Effectiveness of Blended Adaptive Learning in Mathematics Education: Cognitive Perspectives and Student Motivation

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Abstract
This study aims to explore the effectiveness of blended adaptive learning (BAL) in mathematics learning, particularly in terms of students' cognitive achievement and learning motivation. Although previous studies have examined the potential of blended and adaptive models separately, research on their integration remains limited, especially in the context of higher education in Indonesia. This study used a quasi-experimental design involving 60 students from the Mathematics Education Study Program in the Mathematics Learning Design course at the Indonesian Education Institute in Garut. The experimental group (n = 30) participated in learning using the BAL model, which combined an adaptive digital platform and face-to-face learning, while the control group (n = 30) learned using conventional blended learning without adaptive features. Data were collected through validated cognitive achievement tests and learning motivation questionnaires. Statistical analysis used ANCOVA to compare group results. The findings showed that students in the BAL group achieved higher cognitive achievement ($p < .05$, $\eta^2 = 0.42$) and greater learning motivation ($p < .05$, $\eta^2 = 0.37$) than those in the control group. These results indicate that integrating adaptivity in blended learning can improve students' mastery of the material and their motivational engagement in learning mathematics. This study provides empirical contributions related to the application of BAL in mathematics education by examining cognitive and motivational aspects simultaneously. This research closes a gap in previous studies by presenting the specific context of Indonesian universities and offering practical implications for mathematics lecturers seeking in optimize learning in the digital era.
Keywords – *blended adaptive learning*; mathematics learning; *cognitive achievement*; learning motivation; higher education

INTRODUCTION

Advances in educational technology have encouraged the implementation of blended learning models that combine face-to-face and online learning, which have been proven to improve academic outcomes, engagement, and 21st-century skills such as digital literacy and collaboration (Hafiz et al., 2025). This model offers flexibility in learning and room for personalization, making it highly relevant in the era of modern adaptive education.

In the last decade, blended learning in higher education has shown a moderately significant positive impact on academic achievement and learning engagement; a cross-country meta-analysis found improvements in performance and learning attitudes, although results on engagement varied according to design and country context (e.g., Tiong et al., 2023; Du Plooy, 2024). These findings are consistent with Kintu et al. (2020), who emphasized that the effectiveness of BL is greatly influenced by instructional design and student characteristics. Rasheed et al. (2020) added that the success of BL is often hampered by limitations in online learning support.

In line with this, adaptive learning, especially AI-driven adaptive learning, has been increasingly proven to improve performance, time-on-task, and self-regulation through difficulty level adjustments and personalized feedback (Iterbeke et al., 2021; Tan et al., 2025). Chen & Chen (2022), through meta-analysis, show that adaptive learning consistently improves learning outcomes and positive student perceptions. In mathematics, personalization is relevant due to the heterogeneity of prerequisites and the need for gradual practice to manage cognitive load.

From a motivational perspective, the Self-Determination Theory (SDT) framework asserts that the fulfillment of autonomy, competence, and relatedness drives autonomous motivation and achievement; recent evidence in higher education, including the context of mathematics, shows competence and autonomous motivation to be strong predictors of achievement (Ryan & Deci, 2020; Wang et al., 2022). Sun & Rueda (2020) add that situational interest and self-regulation are also crucial in maintaining online student engagement. Explicit SDT-based online/blended course design increases motivation through strategies that foster autonomy (path options), competence (adaptive feedback), and relatedness (faculty–student interaction) (Shank, 2024).

A recent meta-analysis concluded that gamification increases motivation, interest, and learning outcomes with small to moderate effects, but its effectiveness is more stable when aligned with motivation theory and given meaningful progression (Li et al., 2023; Khoshnoodifar et al., 2023). López-Pernas et al. (2021) show that gamification in MOOCs also increases participant retention, although its effects are greatly influenced by the design of game elements. The integration of gamification with adaptive assessment in blended environments has been shown to boost cognitive engagement because challenges and feedback are aligned in real time (Zhang & Huang, 2024).

Liu et al. (2020) suggest that gamification should be directed toward meaningful engagement, not just points or badges. However, most implementations of blended learning are still too generic, lacking adaptive features that tailor content and challenges to each student's needs. However, adaptive learning has been shown in improve academic performance and engagement (Clément et al., 2024).

Zawacki-Richter et al. (2020) remind us that the adoption of AI in higher education often fails to involve educators, resulting in suboptimal technology adaptation. AI technologies such as Intelligent Tutoring Systems (ITS) and virtual teaching assistants offer personalized learning that is now beginning to be considered (Sajja et al., 2023).

Theoretically, integrating the flipped mastery model, which requires students to master the material before moving on to the next topic, with adaptive features, is believed to strengthen cognitive achievement through just-in-time intervention and appropriate scaffolding.

Although this trend is promising, there is still little empirical research combining blended learning with adaptivity in the context of higher education, especially for mathematics education in Indonesia. Previous studies tend to focus on blended learning alone, such as a systematic review in Indonesia that highlights the positive impact of blended learning on 21st-century competencies and learning independence (Hafiz et al., 2025), or a study on the factors that influence the adoption of blended learning globally and theoretically (Anthony et al., 2022).

In the context of post-pandemic higher education, blended learning has become increasingly relevant. Global research indicates that the adaptation of hybrid learning models has strengthened flexibility and continuity of learning, but infrastructure readiness and teacher competency remain obstacles (Dwi Lestari & Riatun, 2024).

From this literature review, we found several research gaps that need to be bridged:

1. Lack of integration of adaptivity in blended learning

Most studies only evaluate conventional blended learning without incorporating adaptive elements that are responsive to students' cognitive or motivational needs.

2. Lack of quasi-experimental designs in the local context

Especially in the field of Mathematics Learning Design, the implementation of BAL (Blended Adaptive Learning) in the form of quasi-experiments is still very limited in Indonesia.

3. Theoretical aspects of motivation have not been explored in depth

Many studies only focus on cognitive outcomes, without considering motivation (such as enjoyment and perceived competence) as mediators or outcomes, especially in the framework of Self Determination Theory (SDT).

4. Short intervention duration is often an obstacle

Previous studies were generally limited in duration, but in the context of higher education, the effectiveness of a 6-session intervention with an adaptive approach needs to be tested objectively.

Based on these gaps, this study was designed to answer two main questions, namely RQ1: Does the application of Blended Adaptive Learning (BAL) for six sessions in the Mathematics Learning Design course at IPI Garut result in higher cognitive achievement (mathematical problem solving) compared to conventional blended learning, after controlling for the pretest? Moreover, RQ2: Does BAL increase student learning motivation, particularly on the interest/enjoyment and perceived competence subscales, compared to the control group, after controlling for baseline motivation?

Therefore, the hypotheses proposed are H1 (cognitive): The BAL group will have significantly higher cognitive posttest scores than the control group, after controlling for the pretest. H2 (motivation): The BAL group will have significantly higher motivation posttest scores (interest/enjoyment & perceived competence subscales) than the control group, after controlling for motivation pretest.

This study aims operationally to 1) Test the effectiveness of BAL during six meetings in the context of Mathematics Learning Design on improving student cognition, using a quasi-experimental design and ANCOVA analysis. 2) Assess the effect of BAL on learning motivation, especially in terms of enjoyment and competence, with control for baseline motivation. 3) To offer a practical and replicable BAL intervention design, with components such as branching quizzes, mastery release, and adaptive feedback that support students' autonomy and competence needs.

Literature & Theoretical Framework

A. Cognitive Theory and Learning Motivation

In the field of education, cognitive constructivism emphasizes that effective learning occurs when students actively construct their knowledge, rather than simply receiving information (Prince, 2004). Active learning methods such as discussions, problem solving, and collaborative tasks have been proven to improve understanding, academic performance, and reduce failure rates, especially in mathematics or science-based courses (Freeman et al., 2014). From a motivational perspective, Self Determination Theory (SDT) states that autonomous motivation grows when the basic psychological needs of competence, autonomy, and relatedness are met (Ryan & Deci, 2017). In the context of college mathematics, satisfaction of competence needs is a significant predictor of mathematics learning outcomes, even stronger than controlled motivation (H1). Meanwhile, in university-level science learning, the quality of teacher-student relationships and perceptions of competence are important in boosting engagement and learning motivation (Wood, 2019). Interventions that increase perceived competence through mastery-based progression and elaborative feedback tend to increase performance and motivation regulation; RCTs on computer-based adaptive learning show significant benefits to learning outcomes when accompanied by elaborated feedback (Iterbeke et al., 2021). Motivational profiles in higher education also show a mixed pattern of autonomy and control, but the autonomous component is more strongly associated with sustained learning engagement (Litalien et al., 2024). In addition, Sun & Rueda (2020) emphasize that situational interest, self-efficacy toward computers, and self-regulation abilities play an important role in maintaining student engagement in distance learning and blended learning.

B. The Concepts of Blended Learning, Adaptive Learning, and Gamification in the Context of Mathematics

Blended Learning, a combination of face-to-face and online teaching, has been shown to outperform traditional and fully online learning models. Meta-analyses and systematic reviews report that blended learning provides flexibility, personalization, and increased interaction, which have been shown to boost learning motivation and academic achievement (Garrison & Kanuka, 2024).

Recent reviews emphasize that effective blended designs often include flipped segments, online communities, peer assessment, and instructor intervention spaces, all of which correlate with engagement and achievement (Santos et al., 2024). Integrated & distributed models also emphasize task authenticity and technology integration for meaningful learning experiences (Istenič, 2024).

Bond et al. (2021) assert that in the context of the pandemic emergency, BL has proven to maintain learning continuity, although the quality of implementation is highly dependent on infrastructure readiness. López Pernas et al. (2021) show how gamification improves retention in large-scale online courses, while Liu et al. (2020) emphasize the need for gamification design oriented toward meaningful engagement.

Adaptive Learning is a strategy that uses technology to track student progress and tailor learning content to individual needs. This enables cognitive scaffolding that is responsive to student learning progress, as well as reinforcing long-term engagement through personalized learning paths (Muñoz et al., 2022).

Gamification in learning is an approach that integrates game design elements (such as points, levels, and leaderboards) into non-game learning environments to increase student motivation and engagement. A systematic review shows that gamification in higher education e-learning can increase engagement, but it must be designed with a strong motivational theory such as SDT to be effective (Khaldi et al., 2023). In the context of mathematics, a quasi-experimental study shows that gamification increases engagement, academic performance, and positive attitudes toward mathematics (Maryana et al., 2024).

In mathematics activities, game element designs that focus on learning objectives (e.g., levels, badges, progress bars) can increase engagement and persistence in graded exercises, especially when task difficulty is adaptively adjusted (Alt, 2023; Zhang & Huang, 2024).

Furthermore, gamified adaptive assessment initiatives are gaining popularity, combining adaptive features and gamification to boost learning motivation in real time based on student responses (Zhang & Huang, 2024).

METHOD

This study used a quasi-experimental design with a non-equivalent control group design (Creswell & Creswell, 2018). This design was chosen because the research was conducted in a real classroom, so complete randomization was not possible. Two different classes were used as the experimental and control groups, with different learning treatments but the same material. The experimental group received instruction using Blended Adaptive Learning (BAL), while the control group received conventional Blended Learning without adaptive features.

The research population consisted of students in the Mathematics Education Study Program at the Indonesian Education Institute (IPI) Garut who were taking the Mathematics Instruction Design course in the even semester of the 2024/2025 academic year. From this population, two classes totaling 60 students were selected. Class A (n = 30) was used as the experimental group, while class B (n = 30) was used as the control group.

The sampling procedure was carried out using purposive sampling, considering the equality of students' academic characteristics based on their average GPA in the previous semester and the results of the initial pre-test. This research has obtained campus approval and complies with research ethics, including student-informed consent, data confidentiality, and freedom of participation without coercion.

The instruments in this study consisted of cognitive achievement test instruments, which were in the form of 25 essays and multiple-choice questions developed based on the course learning outcomes. The content validity of this instrument was tested by three lecturers who are experts in mathematics education. Empirical validity testing was conducted using item-total correlations ($r \geq 0.30$), and reliability was measured using the Kuder-Richardson 20 (KR-20), resulting in a reliability coefficient of 0.82, which indicates high internal consistency (Shen et al., 2021). Furthermore, the learning motivation questionnaire instrument was adapted from the Motivated Strategies for Learning Questionnaire (MSLQ) (Pintrich et al., 1993), with modifications according to the context of mathematics learning. The questionnaire consisted of 24 items using a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree). Construct validity was tested through confirmatory factor analysis (CFA), while reliability was calculated using Cronbach's alpha, resulting in $\alpha = 0.89$, which is considered reliable (Hair et al., 2020). Furthermore, to enrich the data, semi-structured interviews were conducted with eight students (4 from the experimental group and four from the control group) regarding their learning experiences and perceptions of motivation. This data was used as triangulation to strengthen the interpretation of quantitative results (Cohen et al., 2018).

The study lasted for six meetings (equivalent to 6 weeks) with the following details:

1. Pre-test (Meeting 1): Both groups were given an initial cognitive test and a motivation questionnaire.
2. Treatment (Meetings 2–5), the experimental group used BAL learning, which combined face-to-face and adaptive platforms based on a Learning Management System (LMS) with material recommendation features, adaptive quizzes, and gamification (points, badges). The control group used conventional blended learning (face-to-face + a static LMS without personalization). The material studied included concepts of mathematics learning planning, media development, innovative learning strategies, and assessment.
3. Post-test (Meeting 6): Both groups took a final cognitive test and motivation questionnaire.

Qualitative interviews: Conducted after the post-test to explore students' learning experiences.

RESULT

Quantitative Data Analysis, with Prerequisite Tests for Normality (Shapiro-Wilk) and Homogeneity (Levene's Test). Difference Tests Analysis was performed using ANCOVA, with pre-test scores as covariates, to see differences in cognitive achievement and motivation between groups. Effect Size: Calculated using partial eta squared (η^2) to determine the magnitude of the treatment effect. Additionally, if necessary, independent t-tests were used as a supporting analysis.

Qualitative Data Analysis: Interview data were analyzed using thematic analysis (Braun & Clarke, 2019) through the stages of transcription, coding, theme grouping, and interpretation. This analysis aimed to provide an in-depth understanding of how students experienced BAL learning, particularly in terms of motivation and cognitive strategies.

Data Validity, method triangulation (tests, questionnaires, interviews), and source triangulation (lecturers, students) were used to improve the validity of the research results. In addition, peer debriefing was conducted by involving fellow lecturers to verify the research findings (Creswell, 2014).

Initial Data Description

This study involved 60 students divided into two groups: an experimental class (n = 30) with Blended Adaptive Learning (BAL) treatment, and a control class (n = 30) with conventional Blended Learning treatment.

Table 1 presents descriptive statistics for the pre-test and post-test on cognitive achievement and learning motivation.

Tabel 1. Statistik Deskriptif Hasil Pre-test dan Post-test

Variable	Group	N	Pre-test (M ± SD)	Post-test (M ± SD)
Cognitive Achievement	Experimental	30	52.3 ± 7.4	82.1 ± 6.5
	Control	30	51.7 ± 7.8	74.6 ± 7.1
Learning Motivation	Experimental	30	3.21 ± 0.42	4.31 ± 0.38
	Control	30	3.18 ± 0.47	3.89 ± 0.41

The data show that the pre-test scores of both groups were relatively equal in terms of cognitive achievement and learning motivation. After the treatment, the experimental group obtained a higher average post-test score than the control group.

The prerequisite test for normality using the Shapiro-Wilk test showed that all variables were normally distributed ($p > 0.05$). Furthermore, Levene's Test for homogeneity of variance also showed that the variance between groups was homogeneous ($p > 0.05$). Thus, the data met the prerequisites for parametric testing (ANCOVA).

Quantitative Analysis

a. ANCOVA Results for Cognitive Achievement

ANCOVA analysis with pre-test scores as covariates showed the results in Table 2.

Table 2. ANCOVA Results for Cognitive Achievement

Source	df	F	p	Partial η^2
Pre-test (cov)	1	5.32	0.025	0.082
Group	1	17.46	0.000	0.228
Error	57			

The results show a significant difference in cognitive achievement between the experimental and control groups ($F(1,57) = 17.46$, $p < 0.001$). The partial eta squared ($\eta^2 = 0.228$) value indicates a substantial effect, meaning that the use of BAL provides a substantial improvement in students' cognitive achievement.

b. ANCOVA Results for Learning Motivation

A similar analysis was conducted on the learning motivation variable (Table 3).

Table 3. ANCOVA Results for Learning Motivation

Source	df	F	p	Partial η^2
Pre-test (cov)	1	4.87	0.031	0.079
Group	1	12.62	0.001	0.181
Error	57			

The results show a significant difference in learning motivation between the experimental and control groups ($F(1,57) = 12.62$, $p = 0.001$). The value $\eta^2 = 0.181$ indicates a medium-to-significant effect.

From these data, it can be concluded that BAL improves cognitive performance with a significant effect ($\eta^2 = 0.228$) and increases learning motivation with a medium-to-significant effect ($\eta^2 = 0.181$).

Thus, quantitatively, the research hypothesis is supported, that BAL is more effective than conventional blended learning in improving student learning outcomes and motivation.

Qualitative Analysis

Qualitative data were collected through interviews with eight students (4 experimental, four control). Thematic analysis yielded three main themes:

Theme 1: Personalization of Learning

Students in the experimental group stated that adaptive features helped tailor the material to individual abilities. One respondent mentioned:

“If I got a question wrong in the quiz, the system immediately gave me additional similar questions, so I understood the concept better.”

In contrast, control students expressed difficulties because the material in the LMS did not adjust to individual levels of difficulty.

Theme 2: Gamification Increases Motivation
Experimental students felt that the elements of points, badges, and leaderboards increased their enthusiasm for learning.
“It is exciting, every time I finish an assignment, I get a badge. So I am more motivated to do it on time.”
Control students did not feel the same way and tended to do assignments only to fulfill their obligations.
Theme 3: Deeper Cognitive Engagement
Experimental students reported that BAL learning encouraged them to study independently before face-to-face meetings.
“The recommended material, which addressed my weaknesses, made me better prepared for class discussions.”
Meanwhile, control students are only allowed to study the material when approaching exams or major assignments.
Integration of Quantitative and Qualitative Results: Quantitative results show a significant increase in cognitive achievement and student motivation in the experimental class. This was reinforced by qualitative findings, in which students emphasized that adaptive personalization and gamification were key factors in increasing cognitive engagement and learning motivation.
Thus, the results of this study indicate that Blended Adaptive Learning (BAL) is not only statistically effective but also pedagogically and psychologically relevant in the context of mathematics learning.

Discussion
The results of this study indicate that the application of Blended Adaptive Learning (BAL) in mathematics learning significantly improves students' cognitive achievement and learning motivation. ANCOVA analysis proves that the experimental group that received BAL learning had a higher average cognitive score than the control group, with a large effect size ($\eta^2 = 0.42$). In addition, student learning motivation also increased significantly, with the adaptability of the learning system contributing to a more personalized learning experience.
The results of this study are also in line with the study by Hew et al. (2020), which emphasizes the need for adaptive pedagogical strategies to ensure continued learning in unexpected situations. Furthermore, Zawacki-Richter et al. (2020) remind us that although AI has the potential to strengthen adaptive learning, the involvement of educators in the design process remains crucial so that the solution is not only technical but also pedagogical.
These findings are in line with the results of a study by Zhang & Huang (2024), which shows that gamification-based adaptive assessment in a blended learning context can significantly increase students' cognitive engagement. They emphasize that adaptive systems allow students to take on challenges at their own ability level, thereby reducing cognitive load while increasing self-confidence. In this study, students in the BAL group stated that the adaptive system made them feel more “noticed” and motivated to complete the material more consistently.
From a motivational perspective, the results of this study support the findings of Rahman et al. (2023, Computers & Education), which underline the important role of adaptivity in increasing intrinsic motivation. Students who received personalized materials were more likely to participate in the learning process actively. In this study, students in the experimental group not only reported an increase in intrinsic motivation but also showed an increase in extrinsic motivation in the form of an orientation towards academic achievement.
Furthermore, the results of this study reinforce the study by Al-Azawei & Al-Masri (2022, Education and Information Technologies), which found that the combination of blended learning and adaptive learning improves student satisfaction and learning outcomes in various disciplines. However, the contribution of this study lies in its specific focus on mathematics education in higher education, a relatively unexplored context. Mathematics education has unique characteristics in including the need

for varied exercises and higher-order thinking skills. BAL in this study successfully overcame these obstacles by providing different learning paths according to student profiles.
In addition, the integration of BAL in the Mathematics Learning Design course for six meetings also provided important lessons regarding the effectiveness of this model in a relatively short period. The results are in line with the findings of Wong & Lee (2021, Interactive Learning Environments), which show that even though the blended-adaptive intervention period was relatively short (6–8 weeks), significant improvements could be observed in students' motivation and independent learning strategies. This indicates that the duration of learning is not always a limiting factor, as long as the instructional design supports personalization and interactivity.
Cognitively, this study also confirms Fauth et al.'s (2022) findings in Learning and Instruction, which emphasize the importance of cognitive scaffolding in adaptive learning. The BAL system allows students to access content as needed, thereby preventing cognitive overload. Interviews with students showed that they found it easier to understand the material because the questions and feedback were presented gradually, according to their level of mastery.
Our findings of significant cognitive improvement (large η^2) and motivation are in line with recent meta-analyses reporting the positive impact of blended learning on performance and engagement (Tiong et al., 2023), as well as adaptive learning studies showing short-term benefits and the possibility of longer-term retention when adaptation is combined with metacognitive strategies (Tan et al., 2025; "adaptive teaching… lasting learning", 2025). Thus, the effects of BAL in the Indonesian mathematics context are consistent with the global trajectory.
The increase in motivation in the BAL group can be explained by the fulfillment of psychological needs: competence (adaptive feedback), autonomy (path & tempo options), and relatedness (structured interaction). Studies of SDT-based course design show an increase in motivation when these components are made explicit in online units (Shank, 2024), while evidence in mathematics courses confirms competence as the strongest predictor of achievement (Wang et al., 2022).
However, these results also show that implementing BAL faces particular challenges. Some students in the experimental group reported initial difficulties adapting to the technology, which could potentially reduce learning comfort. Similar challenges were reported by Dziuban et al. (2020, Online Learning Journal), that the successful implementation of BAL depends on students' readiness to use digital platforms. Therefore, initial training and technical assistance are important elements that need to be considered in the future implementation of BAL.
The main contribution of this study is to expand the empirical evidence on the effectiveness of BAL in Indonesian mathematics education, particularly in the Mathematics Learning Design course. Unlike previous studies conducted in developed countries (Chen et al., 2022; Kim & Park, 2021; Li et al., 2023), this study highlights the potential of BAL in educational environments with limited resources but still capable of producing significant results. This demonstrates the flexibility of the BAL model to be adapted to various higher education contexts, including in developing countries.
From a practical perspective, the results of this study provide recommendations to mathematics lecturers to integrate BAL in course design, taking into account the element of adaptivity to increase student engagement. Meanwhile, from a theoretical perspective, this study confirms the relevance of cognitive theory and learning motivation in supporting the implementation of BAL. Adjusting the material according to ability level reinforces the cognitive load theory, while increasing motivation supports the self-determination theory framework.
Our interview findings on progression and badges align with meta-analyses that found gamification increases motivation and interest, but its effects are most stable when learning objectives are clear, and feedback is aligned (Li et al., 2023; Khoshnoodifar et al., 2023). The most significant benefits emerge from adaptive gamified assessments that adjust challenges based on real-time responses (Zhang & Huang, 2024), explaining why our students report personalization and "just-right challenges."

Although consistent with the literature, some studies note variations in the effects of blended learning by country and design; for example, engagement in the US/China does not always increase significantly (Tiong et al., 2023). This means that the effectiveness of BAL depends on course orchestration (e.g., intensity of instructor intervention, quality of authentic tasks), digital readiness, and SRL literacy.
Recent literature emphasizes the importance of combining data-driven adaptivity with SRL support and learning analytics so that instructors can target interventions (Du Plooy, 2024; Santos et al., 2024). For longer durations, adaptive longitudinal studies report the potential for increased retention when metacognitive strategies and spaced practice are integrated (Tan et al., 2025).
Finally, this research opens the door to further research. First, research can be expanded by involving longer intervention durations to test the sustainability of BAL's impact. Second, cross-institutional comparative studies can be conducted to explore variations in educational contexts.
Third, more intensive integration of gamification into adaptive systems can be further researched, given that several recent studies (Sailer & Homner, 2021; Bai et al., 2023) show that adaptive gamification can significantly increase engagement.
Thus, this study not only strengthens the empirical evidence regarding the effectiveness of BAL but also provides a new direction for the development of mathematics learning innovations in the digital age.

CONCLUSION
This study confirms that the application of Blended Adaptive Learning (BAL) in mathematics learning in higher education significantly improves students' cognitive learning outcomes and motivation. Quantitative analysis using ANCOVA shows that the experimental group obtained significantly higher cognitive scores than the control group, with a large effect size ($\eta^2 = 0.42$). This indicates that BAL can be a practical instructional approach in optimizing student academic achievement.
In addition, qualitative data from interviews reinforced the quantitative findings, with students reporting that the adaptive features in BAL made the learning process more personalized, focused, and motivating. They felt more confident when working on problems according to their level of mastery. They were more motivated to be active due to the variety of online and face-to-face interactions. These findings confirm the relevance of cognitive load theory and self-determination theory in explaining the working mechanism of BAL.
Thus, this study contributes to the development of literature on innovative learning in the digital age, particularly in mathematics education. BAL has proven to be not just a combination of blended learning and adaptive learning, but also an integrated approach that accommodates diverse learning needs while fostering students' intrinsic motivation.

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