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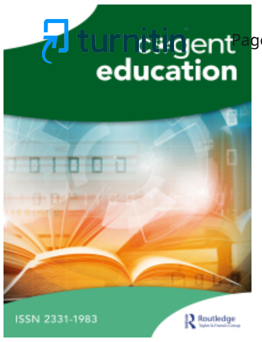

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4 # The impact of blended learning on knowledge, skills and satisfaction in mathematics: a study in Indonesian universities

Khoerul Umam[a], Mohd Isha Awang[b], Bunyamin[a], Ervin Azhar[a] and Ishaq Nuriadin[a]

[a]Universitas Muhammadiyah Prof DR. HAMKA, South Jakarta, Indonesia; [b]Universiti Utara Malaysia, Sintok, Malaysia

35 **ABSTRACT**
34 Blended learning, a method that combines face-to-face and online instruction, has had a significant impact on higher education due to the rapid advancement of information and communication technology. This study analysed the effect of blended
45 learning on students' knowledge, skills and learning satisfaction in mathematics. This
92 study focuses on mathematics learning specifically at the university level. A survey was conducted on 304 Indonesian university students engaged in blended learning
36 for mathematics. Using the Structural Equation Model - Partial Least Squares (SEM-PLS) method, the analysis revealed that blended learning significantly improves students' knowledge and skills, which in turn positively impacts their learning satisfaction. These results were statistically significant. This study offers valuable insights for
54 optimising curriculum design in higher education to enhance the implementation of
56 blended learning and improve the quality of mathematics learning, particularly by highlighting effective teaching methods within this modality.

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32 ## Introduction

The rapid evolution of information and communication technology (ICT) has profoundly reshaped operational paradigms across various institutions, with higher education undergoing a significant transformation (Abdi et al., 2025). Global data indicate a widespread adoption of technology, impacting multiple sectors, including education (Tamphu et al., 2024). This pervasive integration facilitates a learning ecosystem that transcends traditional boundaries of time and location. In higher education, technology has
43 become integral to the learning process, empowering students to access course materials and engage in discussions with both instructors and peers online, thereby diminishing their reliance on the physical classroom as the sole learning environment (Alshurideh et al., 2023). This paradigm shift underscores technology's pivotal role in fostering a more dynamic and adaptive learning culture.

31 The surge in online learning was notably accelerated by the COVID-19 pandemic, which necessitated the closure of educational institutions worldwide and the abrupt shift to remote instruction (Gal &
9 Geiger, 2022; Metaferia et al., 2023). While the pandemic subsided in 2021, enabling the resumption of
73 face-to-face learning, including in Indonesia (Park et al., 2023), the integration of online learning systems within universities has persisted. Students often prefer online learning due to its perceived time-saving benefits and enhanced personal focus (Dolenc & Brumen, 2024). This enduring preference has fostered a
25 new educational culture in Indonesia, characterised by a combination of face-to-face and online learning, commonly known as blended learning (BL) (Dwi Lestari & Riatun, 2024; Hill & Smith, 2023).

80 BL, a hybrid system that integrates face-to-face and online or distance learning, offers flexibility that aligns with student needs, enabling more effective time management and a more conducive study environment (Al-Mekhlafi et al., 2025). In Indonesia, several universities have significantly adopted BL

59 CONTACT Khoerul Umam khoerul.umam@uhamka.ac.id Universitas Muhammadiyah Prof DR. HAMKA, South Jakarta, Indonesia
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environments, with some reaching up to 80% implementation (Prahmana et al., 2021). However, a recognised challenge within BL, particularly in mathematics instruction, lies in the subject's inherent 'higher level of complexity' (Alonso et al., 2025). Students frequently encounter difficulties comprehending digitally delivered mathematics content (Cho & Kim, 2020). The successful implementation of BL hinges on universities' ability to integrate it with their academic policies seamlessly (Buhl-Wiggers et al., 2023). When universities meticulously design curricula to integrate mathematics learning within a blended framework, it can significantly enhance student learning satisfaction and foster the development of both academic and non-academic skills.

Conversely, Hill and Smith (2023) emphasised that the success of a BL system is contingent upon the students' foundational knowledge. Students' ability to effectively integrate the mathematics learning system with BL methods within their academic environment is directly related to their existing knowledge (Awajan et al., 2024). This encompasses their technological proficiency, as students lacking adequate digital skills may face barriers in accessing materials, which can diminish their overall satisfaction with the mathematics learning process (Mullen et al., 2025).

Prior research has investigated the impact of BL on student satisfaction across diverse geographical contexts, including Australia with McCarthy et al. (2025), China with Wu (2024) and Ghana with Bervell and Umar (2020). These studies consistently reported a significant positive influence of BL on student learning satisfaction in these regions. Studies on BL in mathematics have shown that it can improve mathematical thinking skills, foster positive perceptions, enhance learning outcomes and increase self-regulation and problem-solving abilities (Ali, 2024; Awajan et al., 2024; Hill & Smith, 2023; Kyei-Akuoko et al., 2025; Mullen et al., 2025; Sanusi, 2022).

Specifically, within the Indonesian context, research about BL has predominantly focused on factors such as character, attitude, environment, social factors and usage intentions (Dwi Lestari & Riatun, 2024; Prahmana et al., 2021). Furthermore, as noted by Mullen et al. (2025), the efficacy of BL in mathematics instruction remains a subject of considerable debate. Therefore, a significant research gap exists regarding the specific impact of BL on student satisfaction in mathematics learning within Indonesia, particularly concerning the mediating roles of knowledge and skills. This study aims to address a critical gap by exploring factors that influence student satisfaction in the mathematics learning system in Indonesia, particularly given the limited research on these specific factors in recent years. The Indonesian context is particularly pertinent due to its vast and diverse higher education landscape, ongoing digital transformation initiatives and unique cultural approaches to education, which may influence the dynamics of BL adoption and its outcomes. Indonesia's commitment to improving its PISA scores in mathematics, which have historically been low (Gildore et al., 2025). Makes understanding practical pedagogical approaches, such as BL, particularly crucial in this context.

Building upon the assertions of Prifti (2022) and Al-Mekhlafi et al. (2025), which highlight the dependence of BL success on students' knowledge and expertise, this research posits knowledge and skills as mediating factors. The study aims to investigate whether robust knowledge and relevant skills influence Indonesian students' satisfaction with mathematics learning when adopting the BL method. This research is anticipated to serve as a vital reference for educational institutions, enabling them to comprehend the factors influencing student satisfaction in blended mathematics learning. Such insights will facilitate the adjustment of learning methods to better align with student needs and foster a more active academic environment that embraces technology in teaching and learning, especially in mathematics.

Theoretical framework

Blended learning

According to Alonso et al. (2025), BL is an educational system that effectively combines structured face-to-face instruction with flexible, independent online learning, leveraging digital technology. This system offers significant convenience in terms of time, place and learning methods, allowing students to access materials more flexibly (Uz & Uzun, 2018). The flexibility is particularly beneficial for university students, who often manage demanding schedules that encompass both academic and extracurricular commitments. Buhl-Wiggers et al. (2023) noted that BL empowers students with direct instruction from lecturers in class and access to rich digital resources such as videos, interactive modules and online discussion forums, which are highly valuable even in mathematics learning. Students who are comfortable with technology and adept at independent learning tend to report higher satisfaction due to their ability to control their independent learning trend to report higher satisfaction due to their ability to control their learning pace (Tubagus et al., 2020). However, this system also inherently demands a higher level of students' discipline and responsibility (Xu et al., 2023). When coupled with adequate institutional support and a well-designed curriculum, implementing BL can significantly enhance the quality of the learning experience and foster greater student satisfaction (Sukkamart et al., 2025; Višňovská & Cortina, 2025).

The impact of BL on student learning satisfaction has been consistently noted. As mentioned, students' comfort with technology and capacity for independent learning often correlate with increased satisfaction, given their enhanced control over their learning rhythm (Rasheed et al., 2020). Furthermore, students' foundational knowledge of basic concepts critically influences the effectiveness of their engagement with BL (Li et al., 2022). Lazarevic and Bentz (2021) highlight that students with strong knowledge of the subject matter are better equipped to access, comprehend and apply information presented online and face-to-face. This foundational knowledge also encompasses students' expertise in leveraging technology to ensure success within the BL environment (Rasheed et al., 2020). Essential skills such as digital literacy, managing technological devices and effective communication are crucial. Students proficient in technological skills exhibit greater adaptability to the BL system, overcoming potential challenges and significantly enhancing their overall learning satisfaction (Engelbrecht & Borba, 2024).

Blended learning and knowledge

Knowledge, as defined by Gayed (2025), is the accumulation of information, facts, skills and understanding acquired through individual experience and education. Broadly, knowledge can be categorised into declarative knowledge (of facts and concepts) and procedural knowledge (of how to perform tasks) (Barbieri & Booth, 2020). Knowledge forms the primary foundation for effective learning in education, especially in mathematics. By integrating face-to-face and online methods, BL can influence and enrich students' mathematical knowledge (Liebendörfer et al., 2023). This model provides wider access to diverse digital information sources, including learning videos and discussion forums, thereby supporting the enrichment of students' declarative knowledge (Mullen et al., 2025). Moreover, the inherent flexibility of BL empowers students to manage their study time and location according to their individual needs, fostering independent exploration of the material (Kyei-Akuoko et al., 2025). Through online accessible learning, students engage with core mathematical concepts and participate in practical applications that reinforce their holistic understanding.

Several prior studies corroborate the positive effect of BL on knowledge acquisition. For instance, Liebendörfer et al. (2023) demonstrated that BL effectively improved nursing students' knowledge, facilitating better knowledge acquisition and task completion. Similarly, Al-Mekhlafi et al. (2025) found that BL enhanced the public health knowledge of students in Korea, attributing this to easier access to materials and the ability to review challenging sections outside of class time. Kyei-Akuoko et al. (2025) further supported this, suggesting that BL can increase student knowledge by minimising fatigue and enhancing focus. Based on these consistent findings, it is hypothesised that:

H1: Blended Learning (BL) positively affects student knowledge in mathematics learning in Indonesia.

Blended learning and skill

As defined by Sukkamart et al. (2025), it refers to an individual's ability to perform specific tasks or jobs proficiently and efficiently. Skills can encompass cognitive, technical, social or managerial competencies developed through continuous learning and experience (Liu & Yushchik, 2024). Within the educational context, student skills pertinent to BL in mathematics include critical thinking, problem-solving, communication and technical proficiency (Al-Mekhlafi et al., 2025). BL uniquely offers students opportunities to apply their mathematical knowledge through online problem-based activities or case studies, thereby strengthening their critical thinking skills (Kyei-Akuoko et al., 2025). Engelbrecht and Borba (2024). Furthermore, it is highlighted that integrating technology in learning facilitates cross-geographic collaboration via online platforms, fostering the development of broader communication and teamwork skills. Thus, beyond offering flexibility, BL cultivates a rich environment for developing essential mathematical skills in students.

Empirical evidence supports the positive impact of BL on skill development. Moradimokhles and Hwang (2022) found that BL significantly improved students' English language skills. Li et al. (2022) similarly reported that BL substantially enhanced the skills of nursing students, attributing this to the flexibility it provides for students to access materials at their own pace and according to their learning style. Chaeruman et al. (2020) also confirmed that BL significantly influenced skills in clinical supervisor training, noting its higher efficiency. Based on these findings, it is hypothesised that:

H2: Blended Learning (BL) positively affects student skills in learning mathematics in Indonesia.

Knowledge and skill

Knowledge is fundamental to students' mathematics learning process, forming the bedrock for developing more complex skills (Espinoza-Vásquez et al., 2025). In an academic setting, knowledge directly influences how students approach problem-solving, make informed decisions and cultivate professional-level skills (Yang et al., 2022). The critical importance of knowledge lies in its transformative ability to shape skills. A solid knowledge base empowers students to grasp mathematical concepts in depth and effectively apply that understanding to practical situations (Quintos et al., 2025). Furthermore, contemporary education emphasises skills beyond mere cognitive knowledge, expecting students to possess strong problem-solving, critical thinking and adaptive skills to navigate the dynamic changes in mathematics learning (Aoki et al., 2025).

Additionally, robust knowledge enables students to access diverse perspectives, enriching their critical and innovative thinking skills. Thus, knowledge is not merely a passive repository but an active resource that drives innovative skills and effective problem-solving. Research consistently demonstrates this relationship. Murillo-Zamorano and Montanero (2018) found that knowledge significantly influences students' skills in using flipped classrooms. Alfian et al. further substantiated this, reporting a significant impact of knowledge on students' listening and reading comprehension skills. (Murillo-Zamorano & Montanero, 2018) also reinforced this by showing that students' knowledge capacity positively affects their oral presentation skills. Given these established links, it is hypothesised that:

H3: Blended Learning (BL) positively affects students' knowledge in mathematics learning in Indonesia.

Knowledge and learning satisfaction

Knowledge is the primary foundation that influences how students comprehend mathematical material and apply it in various contexts (Ibrahim & Alhosani, 2020). In mathematics, this knowledge extends beyond mere facts and theories to encompass the critical analysis abilities needed to interpret information (Barbieri & Booth, 2020). The deeper and more critical a student understands a concept, the greater their satisfaction in studying mathematics (Krawitz et al., 2025). In this context, student learning satisfaction refers to the level of pleasure and contentment students derive from their mathematics learning experience (Wong & Chapman, 2023). This satisfaction is intrinsically linked to how the knowledge acquired impacts their learning journey (Akbar et al., 2025). Students with profound mathematical knowledge are better equipped to assimilate new material, leading to higher satisfaction. Conversely, a lack of knowledge can lead to confusion, frustration and decreased motivation, ultimately reducing their satisfaction with mathematics learning (Haghighat et al., 2023). Therefore, knowledge is crucial in fostering a positive mathematics learning experience and promoting optimal academic achievement for students.

Prior studies consistently affirm that knowledge influences satisfaction. Haghighat et al. (2023) found that knowledge has a positive impact on learning satisfaction among nursing students. Murillo-Zamorano and Montanero (2018) similarly observe that knowledge significantly influenced students' learning satisfaction in the flipped classroom, mainly because students were required to engage with the material before face-to-face sessions, forming a foundational understanding for discussions. Abuhassna et al. (2020) also emphasised that the quality of knowledge directly affects learning satisfaction in both undergraduate and postgraduate students, enabling them to achieve their academic goals more effectively. Based on these findings, it is hypothesised that:

H4: Knowledge positively affects the mathematics learning satisfaction of students in Indonesia.

Skill and learning satisfaction

Skills represent an individual's learned and experienced abilities, enabling them to perform specific tasks effectively (Smith, 2022). In higher education mathematics, students' foundational skills are crucial to their ability to absorb and apply material effectively in practical situations (Zagouras et al., 2022)(Zagouras et al., 2022)(Zagouras et al., 2022)(Zagouras et al., 2022)(Zagouras et al., 2022). Students who perceive themselves as possessing adequate skills tend to exhibit greater confidence, which enhances their ability to understand mathematical material deeply and fosters a sense of self-satisfaction (Alonso et al., 2025). For example, Murillo-Zamorano and Montanero (2018) reported that students' expertise in utilising flipped classrooms significantly affected their learning satisfaction. This is because students proficient in independent learning and time management skills are better equipped to effectively leverage the flipped classroom model. Yoo and Cho (2020) further demonstrated that skills can lead to higher learning satisfaction within the flipped classroom system, given its perceived efficiency in terms of time and place, allowing students to tailor their learning style. Based on these preceding findings, it is hypothesised that:

H5: Skill positively affects the mathematics learning of students in Indonesia.

Blended learning, knowledge and learning satisfaction

BL, as an instructional method that integrates face-to-face and online components, offers a flexible approach that accommodates diverse student learning styles and fosters deeper knowledge acquisition (Yehia et al., 2022). In supporting mathematics learning, the blended approach enables students to access information independently and flexibly, thereby profoundly increasing their in-depth knowledge. The broader access to materials afforded by BL also facilitates their mathematical exploration of subjects of interest (Okai-Ugbaje et al., 2020). Enhanced knowledge, in turn, strengthens conceptual understanding in applying BL methods and boosts students' confidence in mastering mathematical knowledge due to BL. It is expected to increase their overall learning satisfaction and encourage continuous engagement (Al-Mekhlafi et al., 2025).

Previous research provides empirical support for this mediated relationship. Adi and Fathoni (2020) demonstrated that BL effectively improved nursing students' knowledge. Similarly, Julia et al. (2020) found that BL enhanced the knowledge of public health students in Korea, attributing this to easier material access and the ability to review difficult content outside of class time. Shimizu and Kang (2025) also noted that BL directly influenced learning satisfaction for these students. Furthermore, Roos and Bagger (2024) confirmed that knowledge impacts learning satisfaction in nursing students. Murillo-Zamorano and Montanero (2018) reinforced this by finding that knowledge significantly affected student learning satisfaction in flipped classrooms. Critically, Sojayapan and Khlaisang (2018) specifically highlighted that flipped classrooms could influence student learning satisfaction mediated by knowledge. Synthesising these findings, it is hypothesised that:

H6: Blended learning affects student mathematics learning satisfaction in Indonesia, Mediated by Knowledge.

Blended learning and skill and learning satisfaction

Developing expertise and technological skills is often promoted through blended learning (BL (Zagouras et al., 2022). By utilising BL, students are trained to manage assignment deadlines independently, thereby improving essential self-management skills, which are particularly crucial in mathematics learning due to its often higher level of complexity. Studies have shown a positive impact of BL on skills (Chaeruman et al., 2020). Moradimokhles and Hwang (2022) found that BL influenced students' English language skills in clinical supervisor training attributing its effectiveness to higher efficiency.

Additionally, Fisher et al. (2021) demonstrated that BL positively influences student learning satisfaction in Australian universities. This is often because the blended methods allow students to access materials at any time, facilitating an adjustment of the learning process to their individual needs. Crucially, skill plays a vital role in supporting learning satisfaction. Murillo-Zamorano and Montanero (2018) explained that students' expertise in flipped classrooms can significantly influence their learning satisfaction, as skilled students are better prepared to utilise this learning model effectively. Maarif et al. (2022) also showed that skills lead to higher learning satisfaction in the flipped classroom system. Integrating these insights, it is hypothesised that:

H7: Blended Learning (BL) affects students' mathematics learning satisfaction in Indonesia, mediated by skill.

Blended learning and knowledge and skills

By combining face-to-face instruction with online learning elements, **BL** offers inherent flexibility that enhances student knowledge and facilitates learner interaction (Tubagus et al., 2020). In mathematics, **BL** enables students to learn fundamental concepts independently through digital resources while utilising face-to-face sessions to deepen their understanding of more complex topics (Mullen et al., 2025). The knowledge acquired through such independent learning not only aids students in grasping theoretical concepts but also cultivates vital analytical and problem-solving skills essential for mathematics learning. Empirical evidence supports this link: Wawro and Serbin (2025) showed that **BL** effectively improved nursing students' knowledge. Alonso et al. (2025) also highlighted that **BL** provided easier access to materials, enabling students to repeatedly review difficult sections outside of class to deepen their understanding.

Furthermore, research indicates a direct link between **BL** and skills and knowledge. Roos and Bagger (2024) stated that **BL** influenced students' skills in nursing education, attributing this to the flexibility that allows self-paced learning combined with direct lecturer supervision for practical skill perfection. More specifically, Altas and Mede (2020) found that knowledge significantly influenced students' skills in using flipped classrooms. Hankeln and Prediger (2025) also clarified that knowledge impacts students' listening and reading skills. Given these sequential relationships, it is hypothesised that:

H8: Blended Learning affects students' mathematics learning skills in Indonesia through the mediation of knowledge.

Knowledge, skill and learning satisfaction

Knowledge is the cornerstone of the learning process, particularly in complex disciplines such as mathematics (Gildore et al., 2025). It enables students to comprehend theory and effectively utilise their skills in solving more challenging mathematical problems (Manson & Ayres, 2021). Strong knowledge is, therefore, expected to enhance students' skills, which, in turn, will significantly contribute to their learning satisfaction. Students with robust knowledge tend to develop more effective skills, which directly enhance their process (Strohmaier et al., 2020). Consequently, the synergistic presence of knowledge and skills is anticipated to facilitate a more meaningful mathematics learning experience, leading to higher levels of student satisfaction (Gurmu et al., 2024).

Various studies support this mediated relationship. Pongsakdi et al. (2020) demonstrated a significant influence of knowledge on students' listening and reading comprehension skills. Geiger et al. (2023) similarly showed that students' knowledge capacity positively affected their oral presentation skills, as good knowledge often correlates with increased confidence in conveying information and structuring ideas.

Furthermore, Zhang et al. (2021) found that knowledge influenced learning satisfaction in nursing students, emphasising its critical role in creating an optimal mathematics learning experience for academic achievement. On the other hand, Murillo-Zamorano and Montanero (2018) the study explained that students' expertise in the flipped classroom significantly influenced their learning satisfaction, as skilled students
79 are better prepared for face-to-face sessions due to their foundational independent learning. Shlomo and Rosenberg-Kima (2025) also reinforced that skills lead to higher learning satisfaction in the
50 flipped classroom system. Based on these cumulative findings, it is hypothesised that:

H9: Knowledge influences the learning satisfaction of mathematics students in Indonesia through Skill mediation.

64 ## Research methodology

This study employed a quantitative survey methodology to collect data. The survey was conducted online to gather information from university students across Indonesia who had prior experience with
89 blended learning (BL) in mathematics. A *snowball sampling* method was utilised to recruit participants. This approach involved initially recruiting respondents through social networks, who then referred to other relevant individuals from their contacts. This technique was chosen due to its practicality in accessing specialised and geographically dispersed populations of students engaged in blended mathematics learning. However, it is crucial to acknowledge that the effectiveness and efficiency of snowball sampling are largely contingent on the personal and professional networks of the researcher (Iska et al., 2023). Furthermore, the reliance on self-referral in snowball sampling reduces the sample's representativeness
63 of the findings to the broader student population in Indonesia. This lack of control over the sampling process means the sample may exhibit a degree of homogeneity, potentially overlooking diverse perspectives outside the initially engaged networks (Siri et al., 2020).

66 The questionnaire was structured into several distinct sections. It began with demographic inquiries, such as age, gender and education level, and subsequently posed questions about respondents' experience with the BL method for mathematics. The online format of the survey ensured broad reach and convenient access for participants. A total of 304 students' responses were collected and deemed eligible for analysis, encompassing diverse demographics regarding gender, education level and gadget usage across various islands in Indonesia (See Table 1 for detailed sample characteristics).

The core variables measured in this study included Blended Learning (BL), Knowledge (KN), Skill (SK)
2 and Learning Satisfaction (LS). Each variable was assessed using a 5-point Likert scale, ranging from 1 ('strongly disagree') to 5 ('strongly agree'), to gauge respondents' perceptions across the various dimen-
97 sions investigated. This 5-point scale was specifically chosen for its widespread use and familiarity in educational research, which enhances comparability. Its balanced structure provides sufficient nuance without overwhelming respondents (Riyadh et al., 2019). While acknowledging the ordinal nature of Likert scale data, it is a common practice in PLS-SEM to treat such data as suitable for path analysis, given its non-parametric algorithm and robustness (Hair et al., 2023). A detailed description of each variable and its measurement is provided below:

- **Blended Learning (BL):** This construct measures the perceived effectiveness of BL in the educational
17 context, encompassing aspects such as time flexibility, ease of material access and the seamless

Table 1. Demographic respondents.

Variable	Demographic	Total	Percentage
Gender	Male	142	46.71
	Female	162	53.29
Island	Sumatera	45	14.80
	Java	142	46.71
	Kalimantan	76	25.00
	Sulawesi	41	13.49
Level of education	Undergraduate Degree	221	72.70
	Postgraduate Degree	52	17.11
	Doctoral Degree	31	10.20
Gadgets most often used for studying	Smartphone	129	42.43
	Tablet	21	6.91
	Computer	33	10.86
	Laptop	121	39.80

44 integration of online and face-to-face learning components. The measurement items for BL were adapted from established instruments by Birbal et al. (2018) and Yehia et al. (2022).

- **Knowledge (KN):** This variable assessed students' depth of understanding regarding mathematical concepts delivered through BL. The questions aimed to evaluate conceptual clarity, comprehension of presented material and the ability to apply theoretical knowledge effectively. KN measurement items were adapted from previous studies, notably (Murillo-Zamorano & Montanero, 2018).
- **Skill (SK):** This construct focuses on students' proficiency in solving mathematical problems and their adeptness in utilising the tools and resources available on the BL platform. Relevant items included analytical skills, problem-solving capabilities and applying acquired knowledge in practical situations. Murillo-Zamorano and Montanero (2018) adapted SK measurement items from prior research.
- **Learning Satisfaction (LS):** This variable measures a student's overall satisfaction with their learning experience. It specifically included items evaluating satisfaction with the BL methodology, the teaching efficacy of lecturers and the perceived growth in their knowledge and skills. The LS measurement
12 items were adapted from previous studies by Huang (2021) and Sun et al. (2008).

26 Data analysis was performed using the Structural Equation Model - Partial Least Squares (SEM-PLS)
method. This approach was chosen for its suitability in handling complex research models with multiple independent, mediating and dependent variables, its strong emphasis on predictive power by maximising variance explained in endogenous constructs, and its fewer assumptions regarding data distribution,
62 which is beneficial for data collected via Likert scales (Hair et al., 2023; Henseler et al., 2016). The analysis
39 proceeded in two principal stages, adhering to the recommendations put forth by Hair et al. (2023),
Henseler et al. (2016) and Rigdon et al. (2017).

3 The initial stage involved the Evaluation of the Measurement Model, which was crucial for establish-
96 ing the reliability and construct validity of research variables: Blended Learning, Knowledge, Skill and
Learning Satisfaction. This phase ensured that each construct was consistently and accurately measured.
38 Specifically, reliability was assessed through internal consistency using Cronbach's Alpha (α) and
47 Composite Reliability (CR). Validity was established by examining convergent validity (using Average
Variance Extracted [AVE] values and indicator outer loadings) and discriminant validity (using the
101 Heterotrait-Monotrait Ratio [HTMT] criterion). Additionally, content validity was ensured through expert
review of the questionnaire items to confirm their relevance and comprehensiveness (as noted in the instrument description).

7 Following the successful validation of the measurement model, the subsequent stage involved evalu-
53 ating the Structural Model. This phase focused on testing the hypothesised relationships between the
11 identified latent variables. Path analysis examined both direct and indirect effects among these variables.
To robustly assess the significance of these direct and indirect paths, a bootstrap resampling technique with 5,000 samples was employed. This approach yields a more robust estimation of standard errors, thereby providing a more precise determination of the statistical significance of the effects observed between variables.

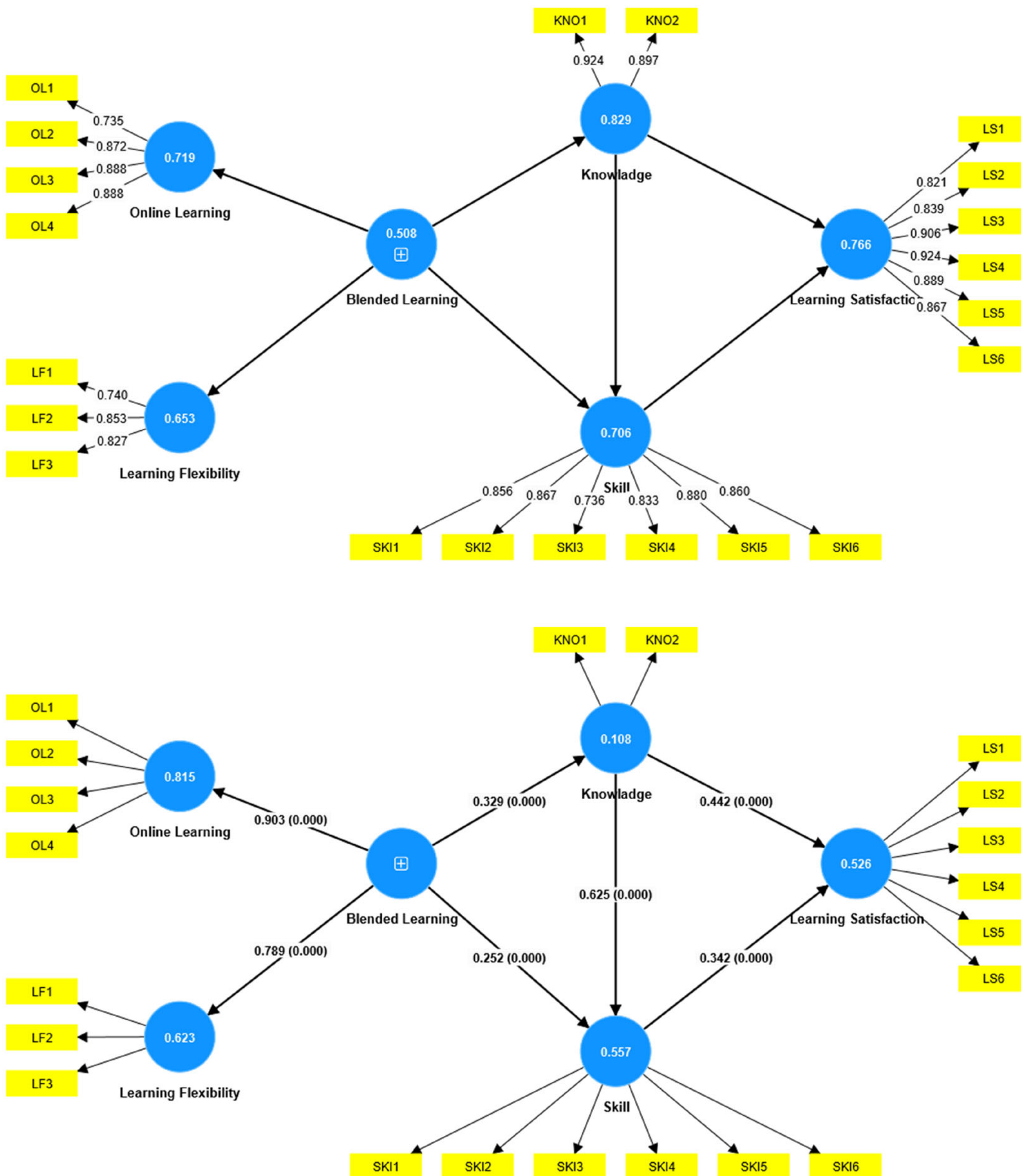

Figure 1. Outer and inner model.

2 ## Results and discussions

This section presents the findings derived from the statistical analysis, specifically focusing on the evalu-
6 ation of the measurement model and the structural model. We detail the outcomes of our investigation
6 into the hypothesized relationships between the identified latent variables, followed by a comprehensive
52 discussion that interprets these results in the context of existing literature and their implication for
mathematics education (Figure 1).

Evaluation measurement model

3 Before proceeding with hypothesis testing, a rigorous evaluation of the measurement model was con-
ducted to establish the reliability and validity of all constructs. This critical step encompassed assess-
16 ments of indicator reliability, internal consistency reliability, convergent validity and discriminant validity,
adhering to the established guidelines outlined by Hair et al. (2023).

Indicator reliability

Indicator reliability was initially assessed by examining the outer loading (OL) values. These values quantify the extent to which the variance of each indicator is explained by its underlying construct, thereby reflecting the reliability of the indicator. The widely accepted recommendation for outer loading values is greater than 0.70. As presented in Table 2, all outer loading values in this study surpassed this threshold, confirming that the indicator reliability for all constructs has been robustly met.

Internal consistency reliability

Cronbach's Alpha (α) and Composite Reliability (CR) were evaluated to ascertain the internal consistency reliability. These metrics are crucial for determining the degree to which indicators designed to measure the same latent construct are intercorrelated and consistent. As shown in Table 2, both the Cronbach's Alpha and Composite Reliability values for all constructs exceeded 0.70. This outcome indicates that the indicators employed in this study are internally consistent and can, therefore, be considered as reliable, fully aligning with the recommendations provided by Hair et al. (2023).

Convergent validity

Convergent validity was assessed through the Average Variance Extracted (AVE). The AVE value indicates the variance a construct explains in its indicators relative to the amount of variance due to measurement error. A high AVE value signifies that all items within a construct converge well, collectively explaining a substantial portion of their shared variance. Manley et al. (2021) recommend an AVE value of 0.50 or higher. As evidenced in Table 2, all AVE values in this study were greater than 0.50, thus confirming the convergent validity of all constructs.

Discriminant validity

Discriminant Validity was examined to ensure that each construct is empirically distinct and sufficiently differentiated from other constructs within the structural model. Henseler et al. (2015) recommend utilizing the Heterotrait-Monotrait (HTMT) for a more robust discriminant validity assessment, with a recommended threshold value below 0.90. Based on the results presented in Table 3, all HTMT values were

Table 2. Outer loading and convergent validity.

Variable	Item	OL	α	CR	AVE
Knowledge	KNO 1	0.924	0.795	0.907	0.829
	KNO 2	0.897			
Blended learning	Online learning	0.789	0.834	0.877	0.508
	Learning flexibility	0.903			
Learning flexibility	LF 1	0.740			
	LF 2	0.853			
	LF 3	0.827			
Online learning	OL 1	0.735			
	OL 2	0.872			
	OL 3	0.888			
	OL 4	0.888			
Learning satisfaction	LS 1	0.821	0.938	0.951	0.766
	LS 2	0.839			
	LS 3	0.906			
	LS 4	0.924			
	LS 5	0.889			
	LS 6	0.867			
Skill	SKI 1	0.856	0.916	0.935	0.706
	SKI 2	0.867			
	SKI 3	0.736			
	SKI 4	0.833			
	SKI 5	0.880			
	SKI 6	0.860			

Notes: OL = Outer Loading, CR = Composite Reliability, AVE = Average Variance Extracted.

Table 3. Discriminant validity

	Blended learning	Knowledge	Learning satisfaction	Skill
Blended learning				
Knowledge	0.400			
Learning satisfaction	0.477	0.785		
Skill	0.526	0.827	0.705	

Table 4. Path coefficients, effect size and collinearity test.

	β	T-stats	P-values	VIF	f2
BL -> KNO	0.329	5.529	0.000	1.000	0.122
BL -> SKI	0.252	6.032	0.000	1.122	0.128
KNO -> LS	0.442	7.186	0.000	2.003	0.206
KNO -> SKI	0.625	14.792	0.000	1.122	0.786
SKI -> LS	0.342	4.985	0.000	2.003	0.123
BL -> KNO -> LS	0.145	4.272	0.000	–	–
BL -> KNO -> SKI	0.206	5.290	0.000	–	–
BL -> SKI -> LS	0.086	3.669	0.000	–	–
KNO -> SKI -> LS	0.214	4.777	0.000	–	–

8 below 0.90. This outcome unequivocally indicates that discriminant validity has been established for all
65 constructs, rendering them suitable for subsequent analysis within the structural model.

Evaluation of the structural model

Hypothesis testing was conducted by analysing the path coefficients and their statistical significance. This was achieved through a robust bootstrapping procedure involving 5000 resamples with a 95%
3 bootstrap confidence level, as Henseler et al. (2016) recommended. The results for each hypothesised path are presented in detail below and are summarised comprehensively in Table 4.

3 **H1: Blended Learning (->) knowledge (β = 0.329, T–stat 5.529, $p<0.001$).** The direct effect of **Blended Learning (BL)** on **Knowledge (KN)** is **positive and significant,** thus providing strong support for **H1.** This finding robustly indicates that the strategic implementation of BL notably enhances stu-
86 dents' knowledge acquisition. This result is consistent with the extant literature, particularly Al-Mekhlafi et al. (2025), which posits that BL facilitates easier access for students to revisit challenging material, thereby deepening their comprehension of complex mathematical concepts. The inherent flexibility of
17 BL, which allows students to learn at their own pace, is profoundly important in mathematics. This subject often demands extensive time and repeated exposure to grasp abstract concepts.

Furthermore, the expensive access to diverse digital resources, such as interactive modules and video tutorials, empowers students to explore various cognitive pathways to internalise complex mathematical ideas. Liebendörfer et al. (2023) underscored that the BL methodology can significantly augment student engagement and motivation, particularly for demanding subjects like mathematics, owing to its adaptable learning styles. This finding aligns with research indicating that knowledge acquired through BL transcends mere theoretical understanding, encompassing the ability to apply concepts in broader contexts.

3 **H2: Blended Learning (->) skill (β = 0.252, T–stat = 6.032, $p<0.001$).** The direct effect of **Blended Learning (BL)** on **Skill (SK)** is also **positive and significant,** confirming the acceptance of **H2.** This
91 underscores that BL effectively contributes to the development of students' mathematical skills. Sukkamart et al. (2025) emphasise the critical role of skills in technology-enhanced learning environments, where BL uniquely enables students to hone the technical and analytical proficiencies indispensable for solving complex mathematical problems. The strategic integration of technology within the learning process, including online discussion forums and computer-based practice exercises, provides
61 invaluable opportunities for students to practice and apply their mathematical knowledge in practical situations actively. This finding resonates strongly with Dwi Lestari and Riatun (2024), who demonstrated that BL substantially increases students' skills by fostering independent learning and the flexible application of relevant abilities across diverse scenarios. In mathematics, BL is instrumental in helping students practice problem-solving as frequently as needed to solidify their understanding.

H3: Knowledge (->) Skill (β = 0.625, T–stat= 14.792, $p < 0.001$) The path from **Knowledge (KN)** to **Skill (SK)** exhibits a powerful positive and significant, profoundly indicating that higher levels of knowledge lead to significant improvements in with the pedagogical principle that a solid and deep knowledge base forms the essential foundation for cultivating higher-order skills, particularly in complex subjects such as mathematics. In mathematics education, an in-depth understanding of theoretical concepts provides students with a robust framework to apply their comprehension in practical contexts, including rigorous problem-solving and comprehensive analysis. According to Sanusi (2022), the knowledge acquired through blended learning, it empowers students to enhance their problem-solving capabilities by providing access to diverse digital resources that facilitate a deeper conceptual understanding. With a firm theoretical grasp, students are better prepared to apply their knowledge in real-world scenarios, which, in turn, sharpens their critical and analytical thinking skills. Moreover, Xu et al. (2023) highlighted that declarative knowledge (factual and conceptual understanding) frequently serves as the indispensable precursor for the development of procedural skills (the 'how-to' aspect of problem-solving), both of which are paramount in mathematics learning. Students with strong declarative knowledge are better equipped to develop procedural skills, such as solving complex equations or intricate problems, which facilitates the emergence of more sophisticated skills, including critical thinking and advanced problem-solving abilities. Within the BL context, students can strategically utilise various online materials to reinforce their foundational knowledge, subsequently applying that knowledge in practice questions or collaborative disciplines that demand high-level problem-solving skills.

H4: Knowledge (->) Learning Satisfaction (β = 0.442, T–stat = 7.186, $p < 0.001$) The relationship between **Knowledge (KN)** and **Learning Satisfaction (LS)** demonstrates strong **positive and significant effect,** suggesting that students who possess greater knowledge exhibit higher satisfaction with their learning experience. This supports **H4.** The acquisition of knowledge during the learning process has a significant and direct impact on learning satisfaction. This suggests that *students with sufficient knowledge are generally more satisfied* with their learning experience. This finding is entirely consistent with research Alrajhi (2024), which indicates that increased knowledge during the learning process contributes to elevated learning satisfaction, particularly when students feel empowered to apply their acquired knowledge in a practical context. In mathematics education, learning satisfaction is frequently correlated with how thoroughly students grasp the concepts taught and their demonstrable ability to solve related problems. When students perceive that they gain a deep understanding of mathematical topics through BL, their satisfaction with the learning process markedly increases as they feel more prepared and confident in navigating academic challenges.

H5: Skill (->) Learning Satisfaction (β = 0.342, T–stat = 4.985, $p < 0.001$). The effect of **Skill (SK)** on **Learning Satisfaction (LS)** is also **significant and positive,** implying that students who acquire better skills tend to be more satisfied with their learning outcomes. Thus, **H5 is supported.** This study found that the skills students acquired during their learning journey significantly contributed to their overall learning satisfaction. Brandsæter and Berge (2025) articulated that students with superior skills in utilising learning technology typically report higher satisfaction with their learning process, primarily because they feel more capable of solving problems and effectively managing their independent learning. In the domain of mathematics education, skills cultivated through BL, such as analytical thinking and problem-solving capabilities, instil greater self-confidence in students, which ultimately translates into increased satisfaction. Students who perceive they have developed competencies relevant to mathematics learning, such as critical and analytical thinking skills, tend to be more satisfied because they can discern the practical applications of their newly acquired knowledge. This finding is further reinforced by Fan et al. (2022), which states that skills developed through technology-based learning substantially increase student satisfaction, as these skills better equip them to confront challenges in real-world challenges.

Indirect effects (mediation analysis)

The study also thoroughly investigated the *indirect effects* to ascertain the crucial mediating roles of *Knowledge* and *Skill* within the hypothesised relationships.

H6: Blended Learning (->) Knowledge (->) Learning Satisfaction (β = 0.145, T–stat = 4.272, $p < 0.001$) The indirect effects of BL on Learning Satisfaction **through Knowledge** are **significant,**

providing clear support for **H6.** This mediation effect profoundly highlights the *important role of knowledge acquisition* in bridging the relationship between BL and students' learning satisfaction, especially in the context of mathematics. BL, with its integrated approach that combines online and face-to-face instruction, provides students with enhanced overall learning satisfaction.

H7: Blended Learning (->) Skill (->) Learning Satisfaction (β = 0.086, T–stat = 3.669, $p < 0.001$). The indirect effects of BL on Learning Satisfaction **through Skill** are also **significant,** although with a comparatively smaller effect size. This finding supports **H7.** This suggests that BL indirectly contributes to learning satisfaction by fostering the development of essential skills. As observed in this study, the acquisition of enhanced skills confers higher self-confidence on students, which, in turn, significantly enhances their satisfaction with the learning experience. Cevikbas and Kaiser (2023) demonstrated that students who feel proficient in utilising learning technology and are adept at applying mathematical concepts tend to be more satisfied with their learning process. In mathematics education, skills cultivated through BL, such as the ability to solve complex problems or fully utilise mathematical technology (e.g. graphing calculators, modelling software), play a pivotal role in increasing students' self-confidence. The more skilled students become in leveraging these tools, the more satisfied they are with their learning outcomes (Engelbrecht & Borba, 2024). This indirect effect illustrates that BL not only confers direct benefits in skill enhancement but also contributes to increased student learning satisfaction through the holistic development of these crucial skills.

H8: Blended Learning (->) Knowledge (->) Skill (β = 0.206, T–stat= 5.290, $p < 0.001$) The indirect effects of BL Sill **through Knowledge** are **significant,** profoundly indicating that **knowledge** acts as a crucial mediator between BL experiences and subsequent skill development. This provides robust support for **H8.** Knowledge indeed serves as a potent mediator in the relationship between BL and skills. As highlighted in the seminal study by Sukkamart et al. (2025), a robust theoretical knowledge base often forms an indispensable foundation for the development of practical skills. In the context of mathematical education, students who possess a deep and nuanced understanding of mathematical theories are inherently better at applying this intricate knowledge in solving real-world problems, which demonstrably improves their skills. BL uniquely provides students with the opportunity to learn mathematics in diverse formats (such as comprehensive texts, engaging videos and interactive exercises), allowing them to learn in a manner that optimally suits their learning styles. The profound knowledge gained through this dynamic method then empowers students to develop superior skills in solving mathematical problems, both within the structured confines of the classroom and in broader, real-life contexts. Tran and O'Connor (2024) found that knowledge acquired through online learning contributed significantly to the development of practical skills in domains requiring deep conceptual understanding, including mathematics.

H9: Knowledge (->) Skill (->) Learning Satisfaction (β = 0.214, T–stat = 4.777, $p < 0.001$) The final mediation effect of knowledge on learning Satisfaction **through Skill** is **significant**, unequivocally indicating that **skills** act as a critical mediator between knowledge acquisition and learning satisfaction. This leads to the acceptance of **H9.** Students who cultivate a deep understanding of mathematical concepts are considerably more likely to effectively apply their knowledge in practical situations, which directly fosters superior skill development. Demir et al. (2022) found that declarative knowledge (theoretical understanding) frequently functions as an important foundation for the development of procedural skills (practical application). In mathematics education, strong theories of knowledge empower students to develop more sophisticated analytical and problem-solving skills, ultimately leading to increased learning satisfaction. Within the BL environment, the profound knowledge gained through various online resources enables students to actively practice and strengthen their skills in solving mathematical problems. These enhanced skills contribute to achieving better academic results and significantly increase students' satisfaction with the learning process, as they feel more prepared and competent to overcome academic challenges effectively.

Coefficients of determination (R2)

The coefficients of determination (R2) quantify the proportion of variance in the endogenous construct that the exogenous construct within the research model can explain. Hair et al. (2023) provide general guidelines, suggesting that R2 values of 0.25, 0.50 and 0.75 typically indicate weak, moderate and strong levels of explanatory power, respectively. As presented in Table 5, the Adjusted R2 values for this study

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Table 5. Coefficient of determination.

	R-square	Adjusted R-square
Knowledge	0.108	0.106
Learning Satisfaction	0.526	0.523
Skill	0.557	0.554

37 demonstrate that the model effectively explains 52.3% of the variation in Learning Satisfaction and 55.4% of the variation in Skill. This suggests that the construct of BL, Knowledge and Skill, as conceptualised in this model, collectively exhibit a moderate to strong explanatory power over student learning satisfaction and skill development in mathematics.

Effect size (f2)

12 Effect Size (f2) is a crucial metric employed in SEM analysis to measure the substantive impact of an exogenous construct on an endogenous construct. This is achieved by calculating the R2 value after systematically removing one exogenous construct at a time (Hair et al., 2023). Li et al. (2022) established widely accepted benchmarks, categorising f2 values of 0.02 as a small effect, 0.15 as a moderate effect, and 0.35 as a significant effect. For example, as detailed in Table 4, the effect of Knowledge on Skill (f2 = 0.786) is substantial, unequivocally indicating a significant and profound contribution of knowledge to skill development. Other relationships, such as Knowledge on Learning Satisfaction (f2 = 0.206), also demonstrate moderate effects, further underscoring the critical importance of knowledge acquisition in shaping positive learning outcomes within an educational context.

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Potential causes for variations from related studies

28 While the findings of this study broadly resonate with the growing body of literature on the benefits of BL, academic rigour demands an acknowledgement that research outcomes can exhibit variations across different studies. Such discrepancies are not uncommon and often stem from a confluence of interconnected factors. One primary contributor to these variations is BL's specific modality and implementation. The precise balance between online and face-to-face components, the specific digital tools and platforms employed, and the underlying pedagogical approaches adopted can differ significantly between studies (Alonso et al., 2025; Engelbrecht & Borba, 2024; Tubagus et al., 2020). For instance, a BL model that is heavily reliant on synchronous online discussions might yield different results than one that emphasises asynchronous interactive modules, leading to distinct impacts on student engagement and learning outcomes.

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87 Furthermore, contextual factors play a profound role in shaping research findings. The cultural and educational landscape in which a study is conducted, including the specific characteristics of the Indonesian higher education system, unique student demographics, pre-existing levels of technological exposure and the prevailing digital infrastructure, can all profoundly influence how students perceive, adapt to and ultimately benefit from BL. These localised variables can create subtle yet significant differences in learning experiences compared to studies conducted in, for example, Western educational settings with different pedagogical traditions or access to technology, highlighting the importance of situated learning perspectives (Kyei-Akuoko et al., 2025). Similarly, discipline-specific nuances are also critical. While this study focused on mathematics, the effectiveness of BL and the precise mediating roles of knowledge and skill may vary across diverse academic disciplines, owing to inherent differences in subject matter complexity, district learning objectives and the unique cognitive skills required for mastery in each field (Liebendörfer et al., 2023).

Finally, variations can also arise from methodological differences, including the operationalisation and measurement of constructs such as ‘Knowledge’, ‘Skill’ and ‘Learning Satisfaction’. Different measurement instruments or scales can capture distinct facets of these constructs, influencing the observed relationship (Engelbrecht & Borba, 2024). Additionally, the characteristics of the student samples, such as their academic background, intrinsic motivation levels or prior digital literacy, while the sampling methodologies employed the use of non-probability sampling, which, as a limitation of this study, can impact

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generalizability, can lead to notable differences in findings when comparing across studies (Meikleham & Hugo, 2020). Acknowledging these potential sources of variation is fundamental for a nuanced interpretation of research findings and for advancing a more sophisticated understanding of BL's complex effectiveness across diverse educational landscapes.

Implications for higher education

The robust findings from this study offer a profound understanding and carry significant, actionable implications for educational institutions, particularly within the dynamic landscape of mathematics teaching in Indonesian higher education. Since BL has been demonstrably proven effective in significantly improving key student learning outcomes, specifically fostering deeper Knowledge acquisition and enhancing essential skills development (as evidenced by the current study's findings, consistent with broader trends noted by Abuhassna et al. (2020)—its strategic application and broader integration within higher education curricula should be a paramount priority for institutions.

Higher education institutions should consider several key focus areas to optimise the utilisation of these valuable research results. Firstly, there is a compelling need to prioritise and invest in developing highly interactive and contextually relevant digital content. This includes designing and providing a rich array of engaging online learning materials, such as sophisticated simulations, adaptive interactive exercises and meticulously produced high-quality video tutorials, all meticulously tailored to address the unique complexities of mathematical concepts (Strohmaier et al., 2020). Such a proactive approach will support diverse learning styles and empower students to achieve self-paced mastery, a critical component of deep learning in mathematics. Secondly, institutions must continue to strengthen and enhance their online learning platforms. This entails investing in robust, intuitively designed and user-friendly digital environments that actively support rich interaction, foster collaborative activities and facilitate effective and timely feedback mechanisms (Shi et al., 2023). These platforms are supplementary tools and the central infrastructure through which BL can deliver flexible access and promote the deep, engaged learning essential for mathematical proficiency.

Furthermore, providing comprehensive technological support necessitates ensuring a seamless and supportive learning experience. This means providing readily available and expert technical assistance to students and lecturers, designed to address technological challenges promptly. By proactively mitigating potential technical frustrations, institutions can ensure that all users can optimally leverage the BL methodology without hindrance. Crucially, a pivotal implication lies in investing in targeted professional development for lecturers. This requires dedicated, ongoing training programs that focus on practical pedagogical approaches for seamlessly integrating the BL strategy (Dwi Lestari & Riatun, 2024). Such training should cover best practices for combining face-to-face and online components, fostering vibrant online discussions, designing authentic assessments within blended learning environments and utilising innovative digital tools to enhance mathematical understanding and application (Cai et al., 2020; Källberg & Roos, 2025). Such comprehensive training is not just about adopting technology; it is about cultivating a more dynamic, relevant and responsive learning environment that genuinely meets the evolving needs of students and comprehensively promotes their holistic intellectual and practical development. By strategically implementing these multifaceted recommendations, higher education institutions in Indonesia can effectively harness the full transformative potential of BL, thereby significantly improving mathematical literacy, fostering crucial skills and ultimately elevating overall student learning satisfaction.

Conclusion

This study set out to analyse the impact of Blended Learning (BL) on students' Learning Satisfaction (LS) in mathematics, specifically examining the mediating roles of Knowledge (KN) and Skill (SK). Our findings reveal that BL has a significant influence on students' knowledge and Skills. Specifically, BL enables students to access learning materials more flexibly and engage with them more deeply, which demonstrably contributes to an enhanced understanding of mathematical concepts. This improved knowledge then directly impacts students' Skills in solving mathematical problems. Furthermore, the enhanced Skill acquired by students directly increases their Learning Satisfaction, as students feel more confident and capable when confronting academic challenges. These results underscore a robust chain effect: BL positively fosters Knowledge, which enhances Skill, ultimately leading to greater Learning Satisfaction.

These findings carry important implications for educational institutions, particularly within the context of mathematics teaching in Indonesian higher education. Since BL has proven effective in improving student learning outcomes, its application should be expanded and further integrated into higher education curricula. For effective policymaking, institutions should prioritise providing more interactive digital content, robust online learning platforms and comprehensive technological support to ensure students can optimally leverage the BL method. Furthermore, investing in targeted training for lecturers to integrate BL more effectively is crucial. This will help cultivate a more dynamic and relevant learning environment that meets student needs and promotes holistic development.

74 Despite these significant contributions, this study is subject to several limitations that warrant consideration for future research. First, the reliance on snowball sampling may have limited the generalizability
70 of our findings, as the resulting sample may not be fully representative of the diverse student popula-
69 tion across Indonesia. Second, adopting a cross-sectional design restricts our ability to capture dynamic
93 changes in student behaviour or identify the long-term effects of BL on learning satisfaction over time.

For future research endeavours, we recommend employing a longitudinal design to better track changes in student attitudes and behaviours within a BL context, as well as using extended representative sampling techniques to enhance the generalizability of findings. Further avenues for exploration could include investigating other influential variables, such as self-regulation, technology acceptance or
15 learning engagement, as potential factors that contribute to the success of BL in fostering student learning satisfaction.

1 Disclosure statement

No potential conflict of interest was reported by the authors.

ORCID

Khoerul Umam http://orcid.org/0000-0003-3853-7025
Mohd Isha Awang http://orcid.org/0000-0002-5304-2744
29 Ervin Azhar http://orcid.org/0000-0003-4629-8693

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