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The Effect of Blended Learning on Students' Knowledge, Skills, and Learning Satisfaction in Learning Mathematics in Indonesian Universities

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The Effect of Blended Learning on Students' Knowledge, Skills, and Learning Satisfaction in Learning Mathematics in Indonesian Universities

Abstract

The rapid development of information and communication technology has affected the education sector, especially in higher education. The blended learning method, which combines face-to-face and online learning, is increasingly popular among students. This study aims to analyze the effect of Blended Learning on students' knowledge, skills, and learning satisfaction in mathematics learning. A survey was conducted on 304 students from various regions in Indonesia who were involved in Blended Learning mathematics learning. The analysis was carried out using the Structural Equation Model - Partial Least Square (SEM-PLS) method. The results of the study indicate that Blended Learning significantly improves students' knowledge and skills, which in turn has a positive impact on their learning satisfaction. This study provides important implications for curriculum development in higher education to optimize the implementation of Blended Learning to improve the quality of mathematics learning.

Kata kunci

Blended Learning, Knowledge, Skills, Learning Satisfaction, Mathematics Education

Introduction

Currently, the rapid development of information and communication technology has changed the way of working in various institutions. One sector that has experienced a major transformation is in educational institutions, especially in higher education (Hashim et al., 2022). According to data from Databoks, in 2022 the use of technology in higher education institutions worldwide will reach 4.9 billion people (Pahlevi, 2022). This development leads to the creation of a learning system that can occur anytime and anywhere. In higher education, the adoption of technology has become an inseparable part of the learning process. Students no longer rely on physical classrooms as the only place to learn (Baig et al., 2022). Where they are able to access lecture materials and discuss, both with lecturers and friends online (Yehia et al., 2022). This shows the role of technology in shaping a new culture in facilitating a more dynamic and adaptive learning experience.

One of the triggers for the increase in online learning is the Covid-19 Pandemic. This pandemic has caused all education sectors to close their institutions and have been forced to conduct online learning (Szopiński & Bachnik, 2022). However, in 2021, there has been a recovery that has caused the spread of the Covid-19 virus to decrease, allowing all educational institutions to conduct face-to-face learning, including in Indonesia (Ssenyonga, 2021). However, even though the Covid-19 pandemic has subsided, in fact the use of online learning systems in universities is still very much attached to both lecturers and students. Students often ask to do online learning again because it is considered to save more time and increase personal focus (Chen, 2023). So this has given rise to a new culture in the education system in Indonesia that combines face-to-face learning with online learning or commonly called blended learning (Gayatri et al., 2022).

Blended learning as a form of learning system by combining face-to-face learning with online or distance learning (Zagouras et al., 2022). He said, this system allows learning methods that can be adjusted to the needs of students because they are able to manage their time and study space more effectively. In Indonesia itself, Yulianti & Sulistiyawati (2020) said, several universities have implemented a blended learning environment of up to 80%. However, Borba et al. (2016) said, one of the obstacles in the blended learning system is in mathematics learning. Mathematics learning is considered to have a higher level of difficulty, so the use of the blended learning system is still in doubt. This is because students often find it difficult to follow mathematics material delivered digitally (Hoyles, 2018). Blended learning will work well if universities are able to integrate it with their academic policies (Bordoloi et al., 2021). If they are able to form a curriculum appropriately to integrate mathematics learning into the blended learning system in their academics, it will create student learning satisfaction including improving their skills both in academic and non-academic environments (Abuhassna et al., 2020).

On the other hand, Rasheed et al. (2020) said, although the blended learning system offers various advantages, the success of this system is highly dependent on the knowledge they have. The knowledge possessed by students will allow them to integrate the mathematics learning system with the Blended learning method in their academic environment (Rasheed et al., 2020). This knowledge includes the skills they have to utilize technology in their mathematics learning system, especially in the blended learning method. Students who lack good technological skills will allow them to face obstacles in accessing and reducing their overall satisfaction with the mathematics learning process (Cihad, 2021).

In previous studies, it has been mentioned by Kang & Kim, (2021), Fisher et al. (2021), Fortin et al. (2019), Bervell & Umar (2020), Previtali & Scarozza (2019) who studied the effect of blended learning on student learning satisfaction in Australia, Singapore, Europe, and Italy. The results showed that blended learning significantly influenced the learning satisfaction of students in Australia, Singapore, Europe, and Italy. However, in Indonesia itself, research related to blended learning is still limited to character, attitude, environment, social factors, and also usage intentions (Mahmud, 2021; Suzianti & Paramadini, 2021; Syaiful Romadhon et al., 2019; Yulianti & Sulistiyawati, 2020). Moreover, Hoyles (2018) stated that the use of the blended learning method in mathematics learning is still in doubt. Therefore, the current researcher intends to further develop blended learning research by adopting student satisfaction factors in the mathematics learning system in Indonesia considering that there are still very few researchers who study these factors, especially in 2024.

Based on the statements previously mentioned by Rasheed et al. (2020) and Cihad (2021), where the success of using the blended learning method in the student environment depends on the knowledge and expertise they have. Therefore, the researcher also adopts knowledge and expertise as mediating factors to find out whether the existence of knowledge and attitudes will change the satisfaction of learning mathematics of students in Indonesia in adopting the blended learning method or not. This research is expected to be a reference for institutions in understanding the factors that influence student satisfaction in learning mathematics using blended learning in order to be able to adjust learning methods that are more appropriate to student needs, as well as encourage a more active academic environment in adopting technology in the teaching and learning process, especially in mathematics.

Literature Review

Blended Learning

According to Zagouras et al. (2022) blended learning is an educational system that combines face-to-face learning with independent online learning that involves the use of digital technology. This system is able to offer convenience in terms of time, place, and learning methods that allow someone to access materials more flexibly (Li et al., 2022). especially for students who are considered to have the highest level of busyness compared to other students, both activities in the academic environment and outside academic activities (Suzianti & Paramadini, 2021). Alkhatib (2018) stated that with the blended learning system, students not only get direct learning instructions through lecturers in class, but are also able to utilize digital resources such as videos, interactive modules, and online discussion forums including in mathematics learning. Students who are familiar with technology and independent learning will tend to be more satisfied because they are able to control their own learning pace (Li et al., 2022). This system also requires students to have a higher level of discipline and responsibility (Rasheed et al., 2020). With the right support from institutions and a good curriculum, the implementation of blended learning can improve the quality of experience and provide higher satisfaction for students (Sarkar et al., 2021).

As previously mentioned, blended learning can have an impact on student learning satisfaction. Students who are familiar with technology and independent learning tend to feel more satisfied because they can control their learning pace (Rasheed et al., 2020). On the other hand, students' knowledge of basic concepts greatly determines how effectively they can use blended learning (C. Li et al., 2019). Lazarevic & Bentz (2021) stated that students who have strong knowledge of the material being studied will be better able to access, understand, and apply information available online or face-to-face. This knowledge refers to students' expertise in using technology to support success in the blended learning system (Rasheed et al., 2020). Digital literacy, the ability to manage technological devices, and communication skills are very Students who have good technological skills will be more adaptable to the learning system. So that this is able to overcome challenges that may arise in the implementation of blended learning to significantly increase student learning satisfaction (Anthonysamy et al., 2020).

Blended Learning and Knowledge

According to Varadarajan (2020) Knowledge is defined as the accumulation of information, facts, skills, and understanding acquired by individuals through experience and education. In general, knowledge can be divided into two, namely declarative knowledge, knowledge of facts and concepts. Second, procedural knowledge, knowledge of how to do something (Demir et al., 2022). In education, knowledge is the main foundation for effective learning, including in mathematics courses. Blended learning that combines face-to-face learning methods with online learning has great potential to influence and enrich students' mathematical knowledge (Li et al., 2019). This model provides wider access to various digital information sources such as learning videos and discussion forums that support the enrichment of students' declarative knowledge (Alkhatib, 2018). In addition, the flexibility in blended learning allows students to organize their time and place of study according to their needs, and gives them the opportunity to explore the material independently (Li et al., 2022). Through learning that is accessed online, students not only learn mathematics from core concepts but are also involved in practical applications that strengthen their knowledge as a whole. In previous studies, it has been discussed as in the study of Li et al. (2019), where blended learning can effectively improve the knowledge of nursing students. They stated that blended learning can make it easier for nursing students to gain knowledge and complete learning tasks better. In line with the research of Kang & Kim (2021) which found that blended learning can improve the knowledge of students in Korea in public health courses. This is because students can access materials more easily and repeat difficult parts outside of class time to deepen their understanding. Turk et al. (2019) also stated that the existence of a blended learning system can influence the increase in knowledge in students. Because blended learning can minimize students from fatigue and increase their focus. Based on the findings above, the researcher hopes that:

H1: Blended Learning has a positive effect on student knowledge in mathematics learning in Indonesia.

Blended Learning and Skill

Burger et al. (2019) defines Skill as an individual's ability to perform certain tasks or jobs well and efficiently. Skills can be cognitive, technical, social, or managerial abilities that develop through learning and experience (Schallock et al., 2018). In the world of education, student skills include critical thinking skills, problem-solving, communication, and technical skills in the blended learning system in the application of learning mathematics (Coyne et al., 2018). Blended learning is able to provide students with opportunities to apply their knowledge in learning mathematics through online problem-based activities or case studies, thereby strengthening their critical thinking skills (Li et al., 2019). Charband & Jafari Navimipour (2016) stated that the integration of technology in the learning process also facilitates cross-geographic collaboration through online platforms. This encourages communication and teamwork skills in a broader context. Thus, blended learning not only provides flexibility but also creates a rich environment for developing students' skills in learning more essential mathematics.

In the research of Moradimokhles & Hwang (2022), it was found that the blended learning system was able to influence students' English language skills. They said that the blended learning system was able to provide a higher increase in students' English skills. In line with the research of Li et al. (2019) which found that blended learning can significantly improve the skills of nursing students. This is because blended learning is able to provide students with the flexibility to access materials according to their speed and learning style. Research by McCutcheon et al. (2018) also confirmed that blended learning was able to significantly influence skills in clinical supervisor learning. They argue that the blended learning method has a higher score because it has a higher level of efficiency. Based on the findings above, researchers hope that:

H2: Blended Learning has a positive effect on student skills in learning mathematics in Indonesia

Knowledge and Skill

Knowledge as a key element in students' mathematics learning process is the foundation for the development of more complex skills (Kim et al., 2019). In an academic environment, knowledge influences the way they solve problems, make decisions, and develop skills to a professional level (Fengler & Taylor, 2019). The importance of knowledge lies in its ability to shape skills. Good knowledge allows students to understand mathematical concepts in depth and apply that understanding to practical situations (Lo Turco & Maggioni, 2022). Moreover, in modern education, the skills expected of students go beyond cognitive knowledge which are expected to have high problem-solving, critical thinking, and adaptation skills to dynamic changes in mathematics learning (Coyne et al., 2018).

In addition, knowledge allows students to access various perspectives that enrich critical and innovative thinking skills. So that knowledge is not only a passive tool, but an active resource that leads to innovative skills and effective problem solving (Franco & DeLuca, 2019). Murillo-Zamorano et al. (2019) in his research also stated that knowledge can significantly influence students' skills in using flipped classrooms. In line with the research of Alfiani et al. (2024), which states that there is a significant influence of knowledge on students' skills in listening and reading comprehension. The research of Murillo-Zamorano & Montanero (2018) also strengthens, Students' knowledge in terms of capacity has been shown to have an effect on improving oral presentation skills. Based on the findings above, the researcher hopes that:

H3: Knowledge has a positive effect on students' mathematics learning skills in Indonesia.

Knowledge and Learning Satisfaction

Knowledge as the main foundation that influences how students understand the material, especially in studying mathematics and applying it to various situations (Varadarajan, 2020). In studying mathematics, this knowledge does not only include facts and theories, but also the abilities needed to analyze information critically (Anderson et al., 2017). The more someone feels critical in knowing something, the more their satisfaction in studying mathematics will increase (Z. Sun et al., 2018). Student learning satisfaction as the level of pleasure and happiness felt by students towards their experience in studying mathematics, including students (Wong & Chapman, 2023). Learning satisfaction lies in how the knowledge they gain affects the overall learning experience (Murillo-Zamorano et al., 2019). Students who have in-depth knowledge of mathematics will be better able to accept the material being studied so that they feel more satisfied. Conversely, lack of knowledge will cause confusion, frustration, and decreased motivation which ultimately reduces their level of satisfaction in studying mathematics (Haghighat et al., 2023). Therefore, knowledge is a critical factor in creating a mathematics learning experience, especially for students to support more optimal academic achievement.

Previous studies have found that knowledge can influence learning satisfaction. Such as research conducted by Haghighat et al (2023) which found that knowledge can influence learning satisfaction in nursing students. In line with the findings of Murillo-Zamorano et al. (2019) who found that knowledge can significantly influence student learning satisfaction in using flipped classrooms. This is because academically students are required to study the material before face-to-face sessions as their main foundation for discussing in class. In the study (Waheed et al., 2016) it was also emphasized that the quality of knowledge can influence learning satisfaction in undergraduate and postgraduate students. Quality knowledge allows students to be more effective in achieving their academic goals. With these findings, the researcher hopes that:

H4: Knowledge has a positive effect on Mathematics Learning Satisfaction of students in Indonesia.

Skill and Learning Satisfaction

Skills are a person's abilities based on learning and experience that enable them to perform certain tasks effectively (Schallock et al., 2018). In studying mathematics in higher education, the skills possessed are the basis for how effectively students can absorb the material and apply it in real situations (Refdinal et al., 2023). Students who feel they have adequate skills tend to feel more confident which allows them to understand mathematics material in depth and bring out their self-satisfaction (Rajabalee & Santally, 2021). As in the study of Murillo-Zamorano et al. (2019), which states that students' expertise in using flipped classrooms can significantly affect student learning satisfaction. This is because students who have independent learning and time management skills tend to be better able to utilize the flipped classroom model. Lopes & Soares (2018) also showed that skills can increase learning satisfaction higher in the flipped classroom system. They consider flipped classrooms to have better efficiency in terms of time and place, so they can adjust their learning style. Based on previous findings, the researcher hopes that:

H5: Skill has a positive effect on Mathematics Learning Satisfaction of students in Indonesia.

Blended Learning and Knowledge and Learning Satisfaction

Blended learning as a learning method that combines face-to-face instruction with online learning provides more flexible knowledge in adjusting students' learning styles (Bordoloi et al., 2021). In supporting the mathematics learning process, the blended learning method allows them to access information independently and flexibly, thereby increasing their knowledge in depth. Wider blended learning access to materials also facilitates their mathematical exploration of subjects of interest (Islam et al., 2022). Better knowledge can strengthen conceptual understanding in applying the blended learning method and increase students' confidence in mastering mathematics material. When students feel that they have good mathematical knowledge in the application of blended learning, it will increase their learning satisfaction and study it continuously (Murillo-Zamorano et al., 2019).

As in the study of Li et al. (2019), where blended learning can effectively improve the knowledge of nursing students. Kang & Kim (2021) also found that blended learning can improve the knowledge of students in Korea in public health courses. Where blended learning is able to provide easier access to materials for students to repeat learning outside of class time. Kang & Kim (2021) also mentioned in their research that blended learning also affects the learning satisfaction of students in Korea in public health courses. On the other hand, research by Haghighat et al (2023) found that knowledge can affect learning satisfaction in nursing students. In line with the findings of Murillo-Zamorano et al. (2019), which states that knowledge can significantly affect student learning satisfaction in using flipped classrooms. The research of Murillo-Zamorano et al. (2019) also emphasized that flipped classrooms can influence student learning satisfaction mediated by knowledge. Based on the findings above, the researcher hopes that:

H6: Blended Learning has an effect on Student Mathematics Learning Satisfaction in Indonesia mediated by Knowledge..

Blended Learning and Skill and Learning Satisfaction

The development of expertise and technological skills is an aspect that is often encouraged through blended learning (Zagouras et al., 2022). By utilizing blended learning, students are trained to manage assignments and deadlines independently, thereby improving self-management skills, especially in mathematics learning which is considered to have a higher level of difficulty (Ndlovu & Mostert, 2018). As in the study of Moradimokhles & Hwang (2022) which states that blended learning can influence students' English language skills. In line with the research of McCutcheon et al. (2018) which states that blended learning can significantly influence skills in clinical supervisor learning. They said that learning through the blended learning method has a higher score because it has a better level of efficiency.

Research by Fisher et al. (2021) found that blended learning can influence student learning satisfaction at universities in Australia. With the blended learning method, students have the ability to access materials at any time and make it easier for them to adjust the learning process to their personal needs. On the other hand, expertise plays a very important role in supporting learning satisfaction. In the research of Murillo-Zamorano et al. (2019) it is explained that students' skills in using flipped classrooms can significantly influence students' learning satisfaction. Lopes & Soares (2018) also showed that skills can increase learning satisfaction higher in the flipped classroom system. Based on the findings above, the researcher hopes that:

H7: Blended Learning has an effect on students' mathematics Learning Satisfaction in Indonesia mediated by Skill.

Blended Learning and Knowledge and Skill

Blended learning that combines face-to-face instruction with online learning elements allows flexibility in improving student knowledge and interacting with fellow users (Alkhatib, 2018). In the process of learning mathematics, blended learning provides an opportunity for students to learn basic concepts independently through digital resources, and use face-to-face sessions to deepen their understanding of more complex ones (Martínez et al., 2020). The knowledge gained through independent learning not only helps students understand the theory, but also builds analytical and problem-solving skills that are essential in their mathematics learning. Such as research conducted by Li et al. (2019), where blended learning can effectively improve the knowledge of nursing students. Kang & Kim (2021) also mentioned that blended learning can provide easier access to materials for students to repeat learning in difficult parts outside of class time to deepen their understanding.

Research by Li et al. (2019) stated that blended learning can influence students' skills in studying nursing education. This is because the flexibility provided by blended learning allows them to learn according to their rhythm and needs, as well as direct supervision from lecturers face to face to help them perfect their practical skills. In addition, research by Murillo-Zamorano et al. (2019) found that knowledge can significantly influence students' skills in using flipped classrooms. The findings of Alfiani et al. (2024) also clarify that knowledge can influence students' listening and reading skills. Based on the findings above, researchers hope that:

H8: Blended Learning has an effect on students' mathematics learning skills in Indonesia through the mediation of Knowledge.

Knowledge and Skill and Learning Satisfaction

Knowledge is the main foundation in the learning process, especially in complex disciplines such as mathematics (Carrillo-Yañez et al., 2018). Knowledge allows students not only to understand the theory but also to utilize their skills in solving more challenging mathematical problems (Masingila et al., 2018). Strong knowledge will strengthen students' skills, which in turn will contribute to students' level of learning satisfaction. Students with good knowledge tend to develop more effective skills, which directly improve their learning process (Kim et al., 2019). So that the existence of knowledge and skills will facilitate students' mathematics learning that is more meaningful and has a higher level of learning satisfaction (Murillo-Zamorano et al., 2019).

Like the research conducted by Alfiani et al. (2024) which states that there is a significant influence of knowledge on students' skills in listening and reading comprehension. In line with the findings of Murillo-Zamorano & Montanero (2018), where students' knowledge in terms of capacity has been shown to have an effect on improving oral presentation skills. When students have good knowledge, they tend to be more confident in conveying information and are able to communicate their ideas in a structured manner. Haghighat et al (2023) also found that knowledge can influence learning satisfaction in nursing students. Knowledge is a critical factor in creating a mathematics learning experience, especially for students to support more optimal academic achievement. On the other hand, Murillo-Zamorano et al. (2019) explained that students' expertise in using flipped classrooms can significantly influence students' learning satisfaction. This is because students who are skilled in utilizing the flipped classroom method tend to be more prepared to face face-to-face sessions, because they have a basic understanding through independent learning. Lopes & Soares (2018) also strengthens, where skills can increase learning satisfaction higher in the flipped classroom system. Based on the findings above, the researcher hopes that:

H9: Knowledge influences the Learning Satisfaction of mathematics students in Indonesia through Skill mediation.

Research Methodology

Data collection in this study was conducted using quantitative survey techniques. This survey was distributed to university students in Indonesia who had been involved in Blended Learning-based mathematics learning. Respondents were selected using the snowball sampling method, where initial respondents were recruited based on social networks, who then recommended other relevant respondents. This technique was used because it is difficult to reach a wider population directly. On the other hand, the success and efficiency of the snowball sampling approach depend almost entirely on the personal or professional contacts of the researcher (Rahman, 2023). The questionnaire used consisted of several parts, including questions about the demographics of respondents (such as age, gender, and education level) as well as questions related to their experiences in using the Blended Learning method for mathematics learning. This survey was conducted online to ensure wider reach and ease of access for respondents. The number of samples collected and eligible for analysis in this study was 304 students based on gender, education level, gadgets used in learning on several islands in Indonesia (See Table 1).

The variables measured in this study include Blended Learning, Knowledge, Skill, and Learning Satisfaction. Each variable is measured using a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree) to assess respondents' perceptions of the various aspects studied. The following is a description of each variable:

1. Blended Learning (BL): Measured by adapting items that assess the effectiveness of using Blended Learning in learning, time flexibility, ease of access to materials, and integration of

online and face-to-face learning. BL measurement uses several previous studies adopted and adapted by Birbal et al. (2018) & Yehia et al. (2022).

2. Knowledge (KN): Measures how well students understand mathematical concepts through Blended Learning. Questions include assessments of conceptual understanding, clarity of the material presented, and ability to apply theory. KN measurement uses several previous studies adopted and adapted by Murillo-Zamorano et al. (2019)

3. Skill (SK): Measures students' skills in solving mathematical problems and using tools provided through the Blended Learning platform. Related items include analytical skills, problem solving, and application of knowledge in practical situations. SK measurement uses several previous studies adopted and adapted by Murillo-Zamorano et al. (2019)

4. Learning Satisfaction (LS): Measured by items that assess students' overall satisfaction with their learning experience, including satisfaction with the Blended Learning method, lecturers' teaching ability, and satisfaction with increasing knowledge and skills. The KN measurement uses several previous studies adopted and adapted by Huang (2021) & P. C. Sun et al. (2008)

Data analysis in this study was carried out using the Structural Equation Model – Partial Least Square (SEM-PLS) method, which was implemented in two main stages according to the recommendations of Hair et al. (2022), Henseler et al. (2016) and Rigdon et al. (2017). The first stage in SEM-PLS is the Evaluation of the Measurement Model to ensure the reliability and construct validity of the research variables, including Blended Learning, Knowledge, Skill, and Learning Satisfaction. This step is important to ensure that each construct is measured consistently and accurately. After the measurement model is evaluated and meets the reliability and validity requirements, the second step is the Evaluation of the Structural Model to test the relationship between the latent variables that have been identified. At this stage, path analysis is carried out to test the hypothesis regarding the direct and indirect effects between variables. To test the significance of the direct and indirect paths, the bootstrap resampling technique with 5000 samples was used. This approach allows for a more robust standard error distribution, providing a more accurate estimate of the significance of the effect between variables.

Table 1. Demographic Respondents

Variable	Demographic	Count	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

Result and Discussion

Uji *Measurement Model (Outer Model)*

Hair et al. (2022) stated that before conducting hypothesis testing in this study, a Measurement Model test was conducted which included indicator reliability, internal consistency reliability, convergent validity and discriminant validity. The indicator reliability test is used to measure how much variance each indicator is explained by its construct, which shows the reliability of the indicator by looking at the outer loading value. The recommended outer loading value is > 0.70. It can be seen in table 2, the outer loading in this study has reached > 0.70 which indicates that the indicator reliability in this study has been met. Table 2 shows the Cronbach's alpha and composite reliability values used in measuring internal consistency reliability to determine the extent to which indicators that measure the same construct are related to each other. Table 2 shows the Cronbach's alpha and composite reliability values are > 0.70, so the indicators used in this study can be declared reliable as recommended by Hair et al. (2022).

In the convergent validity test, the average variance extracted (AVE) value is used to see higher loads in a narrow range which indicates that all items can explain their latent constructs. Manley et al. (2021) stated that the recommended AVE value is at 0.05. In table 2, the AVE value in this study has been > 0.50 so that the convergent validity in this study has been met. Discriminant validity is used to see how much a construct is empirically different from other constructs in the structural model. Henseler et al. (2015) recommend the heterotrait-monotrait ratio (HTMT) for better measurement with a threshold value of 0.90. Based on table 3, the HTMT value is below 0.90, which indicates that discriminant validity has been met and can be used for further analysis.

Table 2. Outer loading and Convergent Validity

Variable	Item	OL	α	CR	AVE
Knowladge	KNO1	0,924	0,795	0,907	0,829
	KNO2	0,897			
Blended Learning	Online Learning	0,789	0,834	0,877	0,508
	Learning Flexibility	0,903			
Learning Flexibility	LF1	0,740			
	LF2	0,853			
	LF3	0,827			
Online Learning	OL1	0,735			
	OL2	0,872			
	OL3	0,888			
	OL4	0,888			
Learning Satisfaction	LS1	0,821	0,938	0,951	0,766
	LS2	0,839			
	LS3	0,906			
	LS4	0,924			
	LS5	0,889			
	LS6	0,867			

Skill	SKI1	0,856	0,916	0,935	0,706
	SKI2	0,867			
	SKI3	0,736			
	SKI4	0,833			
	SKI5	0,880			
	SKI6	0,860			

Table 3. Discriminant Validity

	Blended Learning	Knowladge	Learning Satisfaction	Skill
Blended Learning				
Knowladge	0,400			
Learning Satisfaction	0,477	0,785		
Skill	0,526	0,827	0,705	

Uji *Structural Model*

After evaluating the research model, the next step is to test the hypothesis on the constructs studied in the Structural Model test which includes Indicator Collinearity (VIF), Path Coefficients, Coefficient of determination (R2), and Effect size (f2). First of all, before testing the hypothesis on the Path Coefficients, a test was carried out on the Indicator Collinearity to ensure that there were no collinearity problems between the constructs studied. Becker et al. (2015) suggested a recommended VIF threshold of <5. Table 4 shows that the VIF values for the paths range from 1,000 to 2,003, well below the threshold of 5. This confirms that there is no issue of multicollinearity among the constructs, ensuring the stability of the regression coefficients. To test the hypothesis on the constructs studied, bootstrapping was carried out by 5000 resamples with a bootstrap confidence level of 95% as suggested by Henseler et al. (2016). It can be seen in table 4, Blended Learning on Knowledge ($\beta = 0.329$, T-stat = 5.529) is positive and significant, indicating that the implementation of blended learning strategies positively improves students' knowledge. This can be concluded to accept H1. The findings of this study indicate that Blended Learning has a significant effect on improving students' knowledge. This is in line with the research of Li et al. (2019) which shows that Blended Learning provides easier access for students to repeat difficult material, which ultimately improves their understanding of complex mathematical concepts. In addition, Blended Learning allows students to learn at their own pace, which is very important in learning mathematics, because this subject often requires extra time to understand abstract concepts and requires repetition of material. With wider access to digital resources, such as learning videos and interactive modules, students can explore various ways to understand difficult mathematical concepts. For example, research by Bordoloi et al. (2021) states that the Blended Learning method is able to increase student engagement and motivation to study challenging topics, such as mathematics, because this method provides flexibility in learning styles. This is consistent with research findings showing that knowledge gained through Blended Learning includes not only theoretical understanding but also the ability to apply these concepts in a broader context.

The effect of Blended Learning on Skills ($\beta = 0.252$, T-stat = 6.032) is also positive and significant. It can be concluded that H2 is accepted. Burger et al. (2019) emphasized the importance of skills in technology-based learning, where Blended Learning allows students to hone the technical and analytical skills needed to solve mathematical problems. The use of technology in the learning process, such as online discussion forums and computer-based practice questions, provides opportunities for students to practice and apply mathematical knowledge in real situations. This finding is in line with research by McCutcheon et al. (2018), which shows that Blended Learning provides a significant increase in students' skills, because this method allows them to learn independently and apply relevant skills in various situations. In the context of mathematics learning, students are faced with the challenge of understanding and solving complex problems. The use of Blended Learning helps them practice problem-solving skills more effectively, because students can access the material at any time and repeat the exercises as needed.

Knowledge on Learning Satisfaction (β = 0.442, T-stat = 7.186) shows a strong positive relationship, indicating that students who gain greater knowledge feel more satisfied with their learning experience. Thus accepting H3. The knowledge gained during the learning process has a significant direct effect on learning satisfaction. This indicates that students who feel they have gained adequate knowledge tend to be more satisfied with their learning experience. This finding is consistent with the research of Murillo-Zamorano et al. (2019), which shows that increased knowledge during the learning process contributes to higher learning satisfaction, especially when students feel that they can apply the knowledge they have gained in practical contexts. In mathematics learning, learning satisfaction is often related to how well students understand the concepts taught and their ability to solve the problems faced. When students feel that they gain a deep understanding of mathematics topics through Blended Learning, their satisfaction with the learning process increases, because they feel more prepared and confident in facing academic challenges.

Similarly, Knowledge to Skills (β = 0.625, T-stat = 14.792) showed a very strong effect, indicating that higher knowledge significantly improves students' skills. It can be concluded to accept H4. This finding is in line with the concept that good knowledge is the foundation for developing higher skills, especially in complex subjects such as mathematics. In mathematics learning, in-depth knowledge of theoretical concepts provides a strong foundation for students to apply this understanding in practical contexts, such as problem solving and analysis. According to Li et al. (2019), the knowledge gained through Blended Learning allows students to improve their problem-solving skills because they can access various digital resources that help them understand concepts more deeply. With a strong understanding of theory, students are better prepared to apply their knowledge in real situations, so their critical and analytical thinking skills also improve.

Knowledge not only helps students understand the subject matter but also shapes their ability to apply mathematical concepts to practical contexts. Demir et al. (2022) highlighted that declarative knowledge (knowledge of facts and concepts) is often the basis for the development of procedural skills (how to do something), which are important in mathematics learning. Students who have strong declarative knowledge will be better able to develop procedural skills, such as the ability to solve equations or solve complex mathematical problems. Burger et al. (2019) also showed that in-depth knowledge facilitates the development of more sophisticated skills, such as critical thinking and problem-solving skills. In the context of Blended Learning, students can utilize various materials available online to strengthen their knowledge and then apply that knowledge in practice questions or discussions that require high-level problem-solving skills.

Skills to Learning Satisfaction (β = 0.342, T-stat = 4.985) also has a significant positive effect, meaning that students who acquire better skills tend to be more satisfied with their learning outcomes. Thus, H5 is accepted. This study also found that the skills acquired during learning contributed significantly to students' learning satisfaction. Lopes & Soares (2018) stated that students who have better skills in using learning technology tend to be more satisfied with their learning process, especially because they feel more capable of solving problems and managing independent learning. In the context of mathematics learning, skills developed through Blended Learning, such as analytical and problem-solving skills, provide students with greater self-confidence, which ultimately increases their satisfaction.

Students who feel they have developed skills relevant to mathematics learning, such as critical and analytical thinking skills, tend to be more satisfied because they are able to see practical applications of the knowledge they have acquired. This finding is also supported by research by Rajabalee & Santally (2021), which states that skills developed through technology-based learning significantly increase student satisfaction, because they feel more prepared to face challenges in the real world.

The indirect effect of Blended Learning on Learning Satisfaction through Knowledge (β = 0.145, T-stat = 4.272) is significant. Thus, H6 is accepted. This mediation effect highlights the important role of skills in bridging the relationship between Blended Learning and student learning satisfaction, especially in mathematics learning. Blended Learning, with an approach that combines online and face-to-face learning, provides students with the opportunity to develop better problem-solving skills. In the context of mathematics learning, these skills are very important because students are often faced with questions that require in-depth analysis and application of theory to real situations. Blended Learning, with the provision of online materials such as interactive exercises and simulations, provides space for students to practice and deepen their understanding independently.

The skills acquired through the Blended Learning method then have a positive impact on student learning satisfaction. Rajabalee & Santally (2021) found that students who feel skilled in using learning technology and are able to solve academic problems more effectively tend to be more satisfied with their learning experience. This also applies to mathematics learning, where students who feel more skilled in solving math problems tend to feel more confident and satisfied with the learning process. In addition, the skills developed through Blended Learning not only include technical skills in using math tools, but also include critical thinking and logical skills, which are very important in solving math problems. McCutcheon et al. (2018) stated that Blended Learning encourages students to think independently and apply critical thinking skills in practical situations. This is very relevant in the context of mathematics learning, where students are often faced with complex problems that require a systematic and logic-based approach.

Another indirect relationship is Blended Learning to Skills through Knowledge (β = 0.206, T-stat = 5.290), indicating that knowledge acts as a mediator between blended learning and skill development. It can be concluded that H7 is accepted. Knowledge acts as a strong mediator in the relationship between Blended Learning and Skills. As highlighted in the study by Burger et al. (2019), good theoretical knowledge often forms a solid foundation for the development of practical skills. In the context of mathematics learning, students who have a deep understanding of mathematical theories tend to be better able to apply this knowledge in solving real problems, which improves their skills. Blended Learning provides students with the opportunity to learn mathematical theories in various formats (text, video, interactive exercises), allowing them to learn in a way that best suits their learning style. The knowledge gained from this method then allows students to develop better skills in solving mathematical problems, both in the classroom and in real-life contexts. McCutcheon et al. (2018) found that knowledge gained through online learning contributed significantly to the development of practical skills in areas requiring deep conceptual understanding, including mathematics.

The mediation of Blended Learning on Learning Satisfaction through Skills ($\beta = 0.086$, T-stat = 3.669) is significant, although with a smaller effect. Thus accepting H8. Blended Learning indirectly contributes to learning satisfaction through skill development. As found in this study, better skills provide students with higher self-confidence, which in turn increases their satisfaction with the learning experience. Rajabalee & Santally (2021) showed that students who feel skilled in using learning technology and applying mathematical concepts tend to be more satisfied with their learning process. In mathematics learning, skills developed through Blended Learning, such as the ability to solve problems or use mathematical technology (e.g., graphing calculators, modeling software), play an important role in increasing students' self-confidence. The more skilled students are in utilizing these tools, the more satisfied they are with their learning outcomes. This indirect effect shows that Blended Learning not only provides direct benefits in improving skills but also helps increase students' learning satisfaction through the development of these skills.

The final mediation effect of Knowledge on Learning Satisfaction through Skills ($\beta = 0.214$, T-stat = 4.777) indicates that skills act as a mediator between knowledge and satisfaction. It is concluded that H9 is accepted. Students who have a deep understanding of mathematical concepts are more likely to be able to apply their knowledge in practical situations, leading to better skill development. Demir et al. (2022) found that declarative knowledge (theoretical knowledge) often acts as an important foundation for the development of procedural skills (practical application). In mathematics learning, strong theoretical knowledge helps students develop better analytical and problem-solving skills, which ultimately increases their learning satisfaction. In the context of Blended Learning, the knowledge gained through various online resources allows students to practice and strengthen their skills in solving mathematical problems. These skills not only help students achieve better academic results but also increase their satisfaction with the learning process, as they feel more prepared and able to overcome academic challenges.

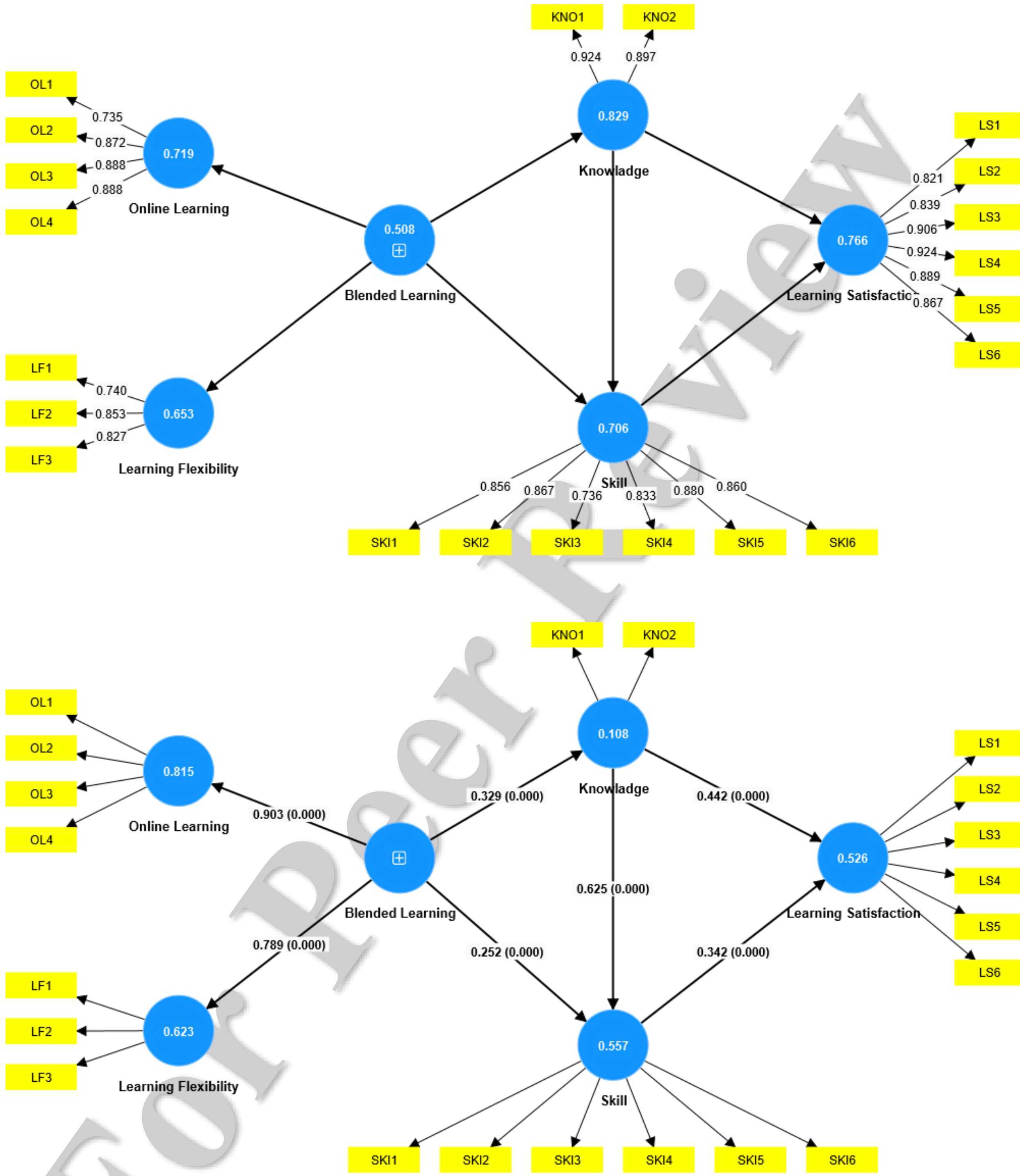

Figure 1. Outer and Inner Model

The coefficient of determination (R2) is used to measure the extent to which exogenous constructs can explain endogenous constructs in research. Hair et al. (2022) stated that R2 values of 0.25, 0.50, and 0.75 indicate weak, moderate, and strong levels. In table 5, R^2 Adjusted shows that this research model is able to explain the variation in Learning Satisfaction by 52.3%, and the variation in Skill by 55.4%. This shows that the knowledge and skills acquired through Blended Learning directly affect student learning satisfaction at a moderate level. Effect size (f2) is used in

SEM testing to measure exogenous constructs in explaining endogenous constructs by recalculating R2 by eliminating one exogenous construct at a time (Hair et al., 2022). At an effect size of 0.02 it is stated to have a small effect, 0.15 is stated to be moderate and 0.35 is stated to be large (Cohen, 1988). For example, the effect of Knowledge on Skills ($f^2 = 0.786$) is very large, indicating that knowledge greatly contributes to skill development. Other relationships, such as Knowledge on Learning Satisfaction ($f^2 = 0.206$), also show moderate effects, further emphasizing the importance of knowledge acquisition in shaping positive learning outcomes.

Table 4. Path Coefficients, Effect Size and Collinearity Test

	β	T-stats	P-Values	VIF	*f*2
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	-	-

Table 5. Coefficient of Determination

	R-square	Adjusted R-square
Knowladge	0,108	0,106
Learning Satisfaction	0,526	0,523
Skill	0,557	0,554

Conclussion

This study aims to analyze the effect of Blended Learning on students' Learning Satisfaction in mathematics learning, by considering the role of Knowledge and Skill as mediators. This study aims to explore how Blended Learning can improve students' knowledge and skills, which ultimately affect their level of satisfaction in the learning process. The results of the analysis show that Blended Learning has a significant direct effect on students' Knowledge and Skill. Blended Learning allows students to access materials more flexibly and deeply, which contributes to an increase in understanding of mathematical concepts. This knowledge then has a direct impact on improving students' skills in solving mathematical problems. In addition, the skills acquired by students also directly increase their Learning Satisfaction, because students feel more confident and able to face academic challenges. The results of the analysis show that Blended Learning has a significant direct effect on students' Knowledge and Skill. Blended Learning allows students to access materials more flexibly and deeply, which contributes to an increase in understanding of mathematical concepts. This knowledge then has a direct impact on improving students' skills in solving mathematical problems. In addition, the skills acquired by students also directly increase their Learning Satisfaction, because students feel more confident and able to face academic challenges.

These findings have important implications for educational institutions, especially in mathematics teaching. Blended Learning has proven effective in improving student learning outcomes, so the application of this method needs to be expanded and deepened in the higher education curriculum. Institutions need to provide more interactive content, digital learning aids, and adequate technological support so that students can optimally utilize the Blended Learning method. In addition, training for lecturers to integrate Blended Learning more effectively is also needed so that the learning process becomes more dynamic and relevant to student needs. This study has several limitations that need to be considered. First, the sampling technique used, such as snowball sampling, can limit the generalizability of the findings because the resulting sample may not be fully representative of the wider student population. Second, this study used a cross-sectional design, which only captures the relationship between variables at one point in time. As a result, changes in behavior or long-term effects of Blended Learning on learning satisfaction cannot be clearly identified.

For future research, it is recommended to use a longitudinal design to measure changes in student attitudes and behavior over time in the context of Blended Learning. In addition, further research can use more diverse and representative sampling techniques so that the results can be more generalized. Future research can also explore other variables such as self-regulation, technology acceptance, or learning engagement as factors that can influence the success of Blended Learning in increasing student learning satisfaction.

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Bukti Konfirmasi Review dan Hasil Review Pertama

tanggal 19 Mei 2025

Azhar Ervin <ervin.azhar.matematika@uhamka.ac.id>

251676324 (Cogent Education) A revise decision has been made on your submission

2 pesan

Cogent Education <onbehalfof@manuscriptcentral.com> 19 Mei 2025 pukul 21.28
Balas Ke: OAED-peerreview@journals.tandf.co.uk
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19-May-2025

Dear Dr Khoerul Umam:

Your manuscript, "The Effect of Blended Learning on Students' Knowledge, Skills, and Learning Satisfaction in Learning Mathematics in Indonesian Universities" submitted to Cogent Education, has now been considered.

We would like to see some substantial revisions made to your manuscript before publication. Therefore, I invite you to respond to our comments and revise your manuscript consistent with the advice provided by our reviewers.

When you revise your manuscript please highlight the changes you make in the manuscript by using the track changes mode or by using bold or coloured text.

To submit a revision, go to https://rp.tandfonline.com/submission/flow?submissionId=251676324&step=1. If you decide to revise the work, please submit a list of changes or a rebuttal against each point which is being raised when you submit the revised manuscript.

If you have any questions or technical issues, please contact the journal's editorial office at OAED-peerreview@journals.tandf.co.uk

Because we are trying to facilitate timely publication of manuscripts submitted to Cogent Education, your revised manuscript should be uploaded by 16-Jun-2025. If it is not possible for you to submit your revision by this date, please let us know as soon as possible.

Once again, thank you for submitting your manuscript to Cogent Education and I look forward to receiving your revision.

Sincerely,
Dr Stephen Darwin
Cogent Education
OAED-peerreview@journals.tandf.co.uk

Reviewer: 1

Comments to the Author
Please revise it according to the suggested improvements in the attached file

Reviewer: 2

Comments to the Author
Please see comments from attached file.

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Azhar Ervin <ervin.azhar.matematika@uhamka.ac.id> 27 Mei 2025 pukul 16.21

Kepada: Khoerul Umam <khoerul.umam@uhamka.ac.id>

[Kutipan teks disembunyikan]

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1. Title

Strengths: Highlighting the influence of blended learning on knowledge, skills, and satisfaction in mathematics education at Indonesian universities, the title appropriately captures the essence of the study.

Advice: To improve clarity, think about making the title simpler and more understandable. For instance: "The Impact of Blended Learning on Knowledge, Skills, and Satisfaction in Mathematics: A Study in Indonesian Universities"

2. Abstract

Strengths: Highlighting the beneficial effects of blended learning on knowledge and satisfaction, the abstract provides a concise overview of the study's goals, methodology (SEM-PLS), and main conclusions.

Recommendation: The statistical significance of the results should be briefly mentioned in the abstract.

Elaborating on the implications for teaching methods.

Amendment: substitute "provides important implications for curriculum development" by "provides valuable insights for optimizing curriculum design" .

Addition: This study focuses on mathematics learning specifically at the university level.

3. Keywords

Suggestion: Consider including more focused keywords like "Structural Equation Modeling" and "Mathematics Education."

Base: These keywords increase relevance and searchability.

4. Introduction

Advantages: The motivation behind the research is stated clearly, and the development of blended learning after COVID-19 is highlighted.

Make a suggestion: To draw attention to the research gap, include a more specific problem statement.

To provide context for the research, summarize the key conclusions of earlier studies on blended learning in mathematics.

The solution is to use "higher level of complexity" instead of "higher level of difficulty" when describing difficulties with learning mathematics.

Addition: Briefly state why the Indonesian context is unique or important to study.

5. Literature Review: Thorough and well-structured, discussing how blended learning affects knowledge, abilities, and satisfaction.
Make a suggestion:
Sort related research by subject (e.g., studies on satisfaction, skill development, and knowledge enhancement).
A summary table of the main conclusions from pertinent studies is included for added clarity.
Add-on: To be current, include more recent research, particularly after 2023.
Fix: Occasionally, there are sudden changes in the subject. To make things more coherent, use transitions.
Examine cited studies for possible bias, particularly if they employ non-probability sampling techniques.
6. Methods: explains variables, statistical analysis, and data collection in detail.
Make a suggestion: Explain why the SEM-PLS approach is appropriate for this investigation.
Discusses the possible drawbacks of snowball sampling in greater detail.

Fix: Replace "snowballing sampling may limit generalizability" with "snowballing sampling may reduce sample representativeness".

Addition: Explain the rationale for choosing a 5-point Likert scale and its implications for data interpretation.

Clarify how to assess the reliability and validity of data.

7. Results: The statistical results are presented in an organized and understandable manner.
Make a suggestion:
Use visual aids such as charts to improve data interpretation.
For easier reading, list the main conclusions in bullet points.
Revision: Do not use the same justification in several results subsections.
Supplement: Briefly explain how these results support or contradict the body of existing literature.

8. Discussion: it offers profound understanding and educational value.
Make a suggestion: Describe how the results will be used in higher education.
Talk about potential causes for variations from related studies.

Fix: Replace "This shows that students who feel they have enough knowledge tend to be more satisfied" with "This shows that students who have enough knowledge show higher satisfaction".

Addition: Highlights how blended learning can be optimized explicitly in mathematics education.

9. Conclusion

Strengths: Clearly states key findings and implications.

Suggest:

Clearly distinguish the summary of findings from the actual recommendations.

Address the limitations of the study and suggest areas for future research.

Fix: Replace "Analysis shows that Blended Learning has a significant direct impact" with "Analysis shows that Blended Learning has a significant impact..."

Addition: Highlight how these findings can inform policy-making in Indonesian higher education.

10. References and Citations
Strengths: A wide range of references that address various topics and viewpoints.
Make a suggestion:
Utilize the APA citation style consistently throughout the work.
Any out-of-date references should be updated, particularly those that date prior to 2020.
Fix: Check that the URLs supplied for online sources are correct.
Supplement: Where available, incorporate current meta-analyses of blended learning in mathematics teaching.

Bukti konfirmasi submit revisi pertama, respon kepada reviewer, dan artikel yang diresubmit

30 Juni 2025

Khoerul Umam <khoerul.umam@uhamka.ac.id>

Cogent Education - 251676324.R1 - changes required to your submission

2 messages

Cogent Education <onbehalfof@manuscriptcentral.com> Mon, Jun 30, 2025 at 5:31 PM
Reply-To: OAED-peerreview@journals.tandf.co.uk
To: khoerul.umam@uhamka.ac.id

30-Jun-2025

Dear Dr Khoerul Umam:

Your above referenced manuscript, entitled "The Impact of Blended Learning on Knowledge, Skills, and Satisfaction in Mathematics: A Study in Indonesian Universities" requires some further changes before it is ready for review by Cogent Education.

1) Missing clean anonymous version

I noticed that you have not uploaded a clean anonymous version of your manuscript. Please be kind to upload as per journal's requirements.

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You may contact the Editorial Office if you have further questions.

Sincerely,

Cogent Education Editorial Office

Khoerul Umam <khoerul.umam@uhamka.ac.id> Mon, Jun 30, 2025 at 8:12 PM
To: OAED-peerreview@journals.tandf.co.uk

Dear Cogent Education Editorial Office,

Thank you for your prompt feedback.

We would like to confirm that we have now uploaded the revised manuscript, including the clean anonymous version and the track changes version with all author-identifying comments removed.

We appreciate your continued support and look forward to the next steps in the review process.

Sincerely,

Dr. Khoerul Umam

[Quoted text hidden]

Khoerul Umam <khoerul.umam@uhamka.ac.id>

Submission received for Cogent Education (Submission ID: 251676324)

1 message

OAED-peerreview@journals.tandf.co.uk <OAED-peerreview@journals.tandf.co.uk> Mon, Jun 30, 2025 at 8:10 PM
To: khoerul.umam@uhamka.ac.id

Dear Khoerul Umam,

Thank you for your submission.

Submission ID	**251676324**
Manuscript Title	**The Impact of Blended Learning on Knowledge, Skills, and Satisfaction in Mathematics: A Study in Indonesian Universities**
Journal	**Cogent Education**
Article Publishing Charge (APC)	**USD $2195.0 (plus VAT or other local taxes where applicable in your country)**

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Kind Regards,
Cogent Education Editorial Office

The Impact of Blended Learning on Knowledge, Skills, and Satisfaction in Mathematics: A Study in Indonesian Universities

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Abstract

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 learning on students' knowledge, skills and learning satisfaction in mathematics. This study focuses on mathematics learning specifically at the university level. A survey was conducted on 304 Indonesian university students engaged in blended learning 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 optimising curriculum design in higher education to enhance the implementation of blended learning and improve the quality of mathematics learning, particularly by highlighting effective teaching methods within this modality.

Key words: Blended Learning, Knowledge, Skill, Learning Satisfaction, Higher Education Mathematics Education, Structural Equation Model.

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 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., 2020). This paradigm shift underscores technology's pivotal role in fostering a more dynamic and adaptive learning culture.

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 & Geiger, 2022; Metaferia et al., 2023). While the pandemic subsided in 2021, enabling the resumption of 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 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).

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 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 & 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., 2023).

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 & 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 (Sanusi, 2022; Mullen et al. 2023; Hill & Smith 2023; Awajan et al. 2024; Ali 2024; Kyei-Akuoko et al. 2025).

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., (2023), 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 discussions 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 (X. Li et al., 2022). Lazarevic & 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., 2023). 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 & Borba, (2024) Further, 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 & Hwang, (2022) found that BL significantly improved students' English language skills. Li et al (2019) 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., 2024). 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., 2024).

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 (Franco & DeLuca, 2019). Research consistently demonstrates this relationship. (Murillo-Zamorano & Montanero, 2018) found that knowledge significantly influences students' skills in using flipped classrooms. Alfian et al. (2024) 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 & Montanero (2018) similarly observe that knowledge significantly influenced students' learning satisfaction in 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 & 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 & 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 & 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 & Kang (2025) also noted that BL directly influenced learning satisfaction for these students. Furthermore, Roos & Bagger (2024) confirmed that knowledge impacts learning satisfaction in nursing students. Murillo-Zamorano & Montanero (2018) reinforced this by finding that knowledge significantly affected student learning satisfaction in flipped classrooms. Critically, Sojayapan & Khlaisang (2020) 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 & 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 & 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., 2023). 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 & 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 & 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 & Mede (2021) found that knowledge significantly influenced students' skills in using flipped classrooms. Hankeln & 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 & Montanero (2018) the study explained that students' expertise in the flipped classroom significantly influenced their learning satisfaction, as skilled students are better prepared for face-to-face sessions due to their foundational independent learning. Shlomo & Rosenberg-Kima (2024) also reinforced that skills lead to higher learning satisfaction in the 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.

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 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 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).

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).

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

The core variables measured in this study included Blended Learning (BL), Knowledge (KN), Skill (SK), 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 dimensions 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 context, encompassing aspects such as time flexibility, ease of material access, and the seamless 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 & 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 items were adapted from previous studies by Huang, (2021) and Sun et al. (2008).

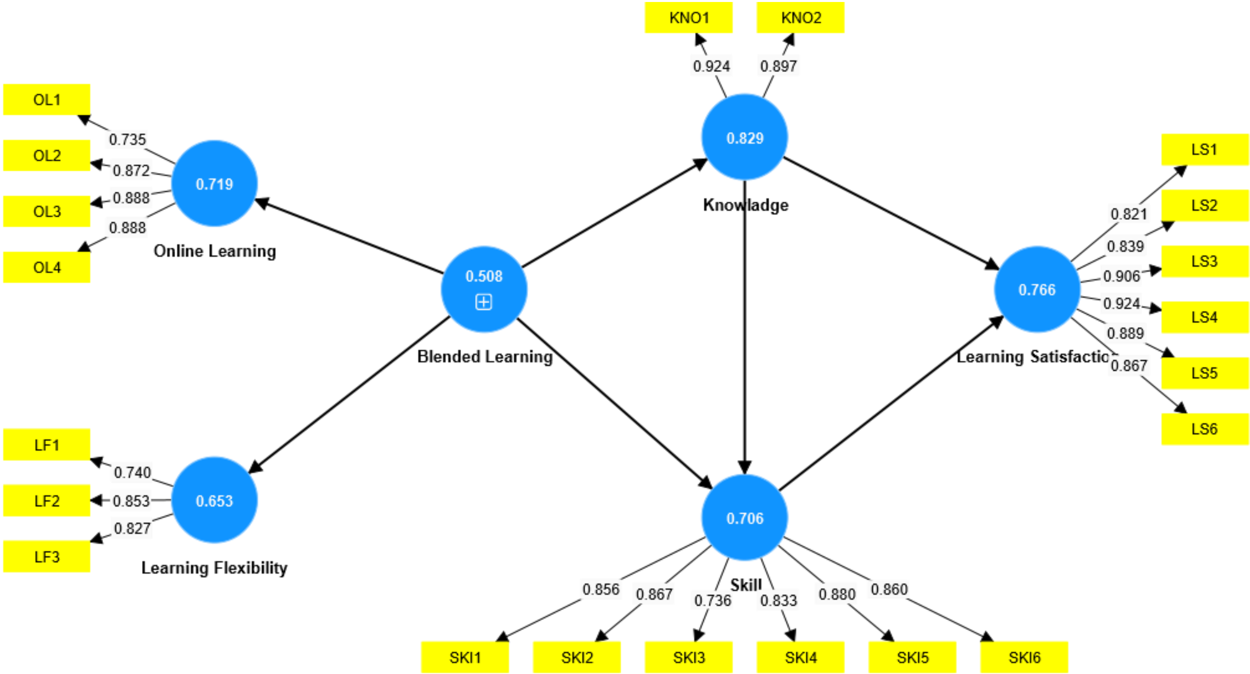
Data analysis was performed using the **Structural Equation Model - Partial Least Squares (SEM-PLS) method.** This approach was chosen for its suitability in handling complex research models with multiple independent, mediating, and dependent variables, its strong emphasis on predictive power by maximising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

The initial stage involved the **Evaluation of the Measurement Model,** which was crucial for establishing 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. Specifically, **reliability** was assessed through internal consistency using **Cronbach's Alpha** (α) and **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 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).

Following the successful validation of the measurement model, the subsequent stage involved evaluating **the Structural Model.** This phase focused on testing the hypothesised relationships between the 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.

Results and discussions

This section presents the findings derived from the statistical analysis, specifically focusing on the evaluation of the measurement model and the structural model. We detail the outcomes of our investigation into the hypothesized relationships between the identified laten variables, followed by a comprehensive disscussion that interpretes these results in the context of existing literature and their implication for mathematics education.



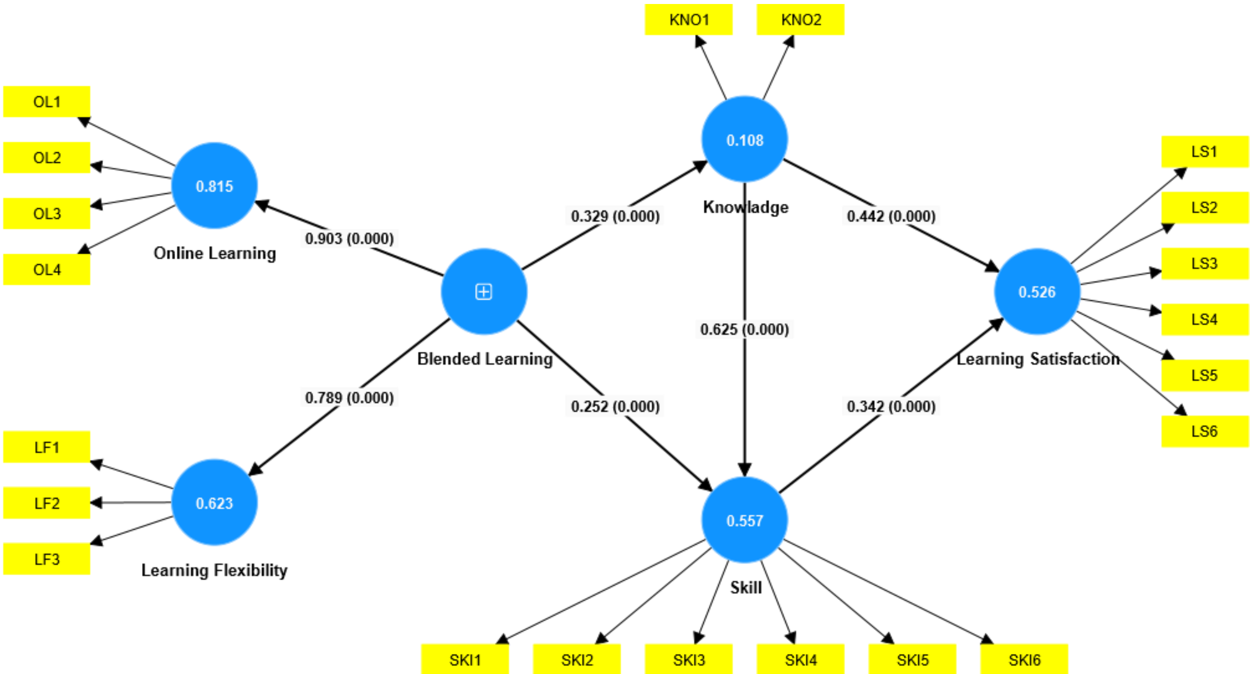


Figure 1. Outer and Inner Model

Figure 1. Outer and Inner Model

Evaluation Measurement Model

Before proceeding with hypothesis testing, a rigorous evaluation of the measurement model was conducted to establish the reliability and validity of all constructs. This critical step encompassed assessments 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 below 0.90. This outcome unequivocally indicates that discriminant validity has been established for all constructs, rendering them suitable for subsequent analysis within the structural model.

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	Online Learning	0,789	0,834	0,877	0,508
Learning	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	0888			
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:

	Blended Learning	Knowledge	Learning Satisfaction	Skill
Blended Learning				
Knowledge	0,400			
Learning Satisfaction	0,477	0,785		
Skill	0,526	0,827	0,705	

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% 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.

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 students' 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 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.

H2: Blended Learning (->) skill ($\beta=0.252$, 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 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 invaluable opportunities for students to practice and apply their mathematical knowledge in practical situations actively. This finding resonates strongly with Dwi Lestari & 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 ($\beta=0.625$, 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 ($\beta=0.442$, 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 ($\beta=0.342$, 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 & 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 the 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 ($\beta=0.145$, 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 & 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 & 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.

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	-	-

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. (2022) 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 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.

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

Effect Size (f2)

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). Y. Li (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.

Potential Causes for Variations from Related Studies

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.

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 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.

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 of our findings, as the resulting sample may not be fully representative of the diverse student population across Indonesia. Second, adopting a cross-sectional design restricts our ability to capture dynamic 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 learning engagement, as potential factors that contribute to the success of BL in fostering student learning satisfaction.

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The Effect of Blended Learning on Students' Knowledge, Skills, and Learning Satisfaction in Learning Mathematics in Indonesian Universities

The Impact of Blended Learning on Knowledge, Skills, and Satisfaction in Mathematics: A Study in Indonesian Universities

Abstract

The rapid development of information and communication technology has affected the education sector, especially in higher education. The blended learning method, which combines face-to-face and online learning, is increasingly popular among students. This study aims to analyze the effect of Blended Learning on students' knowledge, skills, and learning satisfaction in mathematics learning. A survey was conducted on 304 students from various regions in Indonesia who were involved in Blended Learning mathematics learning. The analysis was carried out using the Structural Equation Model - Partial Least Square (SEM-PLS) method. The results of the study indicate that Blended Learning significantly improves students' knowledge and skills, which in turn has a positive impact on their learning satisfaction. This study provides important implications for curriculum development in higher education to optimize the implementation of Blended Learning to improve the quality of mathematics learning.

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 learning on students' knowledge, skills and learning satisfaction in mathematics. This study focuses on mathematics learning specifically at the university level. A survey was conducted on 304 Indonesian university students engaged in blended learning 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 optimising curriculum design in higher education to enhance the implementation of blended learning and improve the quality of mathematics learning, particularly by highlighting effective teaching methods within this modality.

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Kata kunci

Blended Learning, Knowledge, Skills, Learning Satisfaction, Higher Mathematics Education, Structural Equation Model.

Introduction

Currently, the rapid development of information and communication technology has changed the way of working in various institutions. One sector that has experienced a major transformation is in educational institutions, especially in higher education (Hashim et al., 2022). According to data from Databoks, in 2022 the use of technology in higher education institutions worldwide will reach 4.9 billion people (Pahlevi, 2022). This development leads to the creation of a learning system that can occur anytime and anywhere. In higher education, the adoption of technology has become an inseparable part of the learning process. Students no longer rely on physical classrooms as the only place to learn (Baig et al., 2022). Where they are able to access lecture materials and discuss, both with lecturers and friends online (Yehia et al., 2022). This shows the role of technology in shaping a new culture in facilitating a more dynamic and adaptive learning experience.

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 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., 2020). This paradigm shift underscores technology's pivotal role in fostering a more dynamic and adaptive learning culture.

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One of the triggers for the increase in online learning is the Covid-19 Pandemic. This pandemic has caused all education sectors to close their institutions and have been forced to conduct online learning (Szopiński & Bachnik, 2022). However, in 2021, there has been a recovery that has caused the spread of the Covid-19 virus to decrease, allowing all educational institutions to conduct face-to-face learning, including in Indonesia (Ssenyonga, 2021). However, even though the Covid-19 pandemic has subsided, in fact the use of online learning systems in universities is still very much attached to both lecturers and students. Students often ask to do online learning again because it is considered to save more time and increase personal focus (Chen, 2023). So this has given rise to a new culture in the education system in Indonesia that combines face-to-face learning with online learning or commonly called blended learning (Gayatri et al., 2022).

Blended learning as a form of learning system by combining face-to-face learning with online or distance learning (Zagouras et al., 2022). He said, this system allows learning methods that can be adjusted to the needs of students because they are able to manage their time and study space more effectively. In Indonesia itself, Yulianti & Sulistiyawati (2020) said, several universities have implemented a blended learning environment of up to 80%. However, Borba et al. (2016) said, one of the obstacles in the blended learning system is in mathematics learning. Mathematics learning is considered to have a higher level of difficulty, so the use of the blended learning system is still in doubt. This is because students often find it difficult to follow mathematics material delivered digitally (Hoyles, 2018). Blended learning will work well if universities are able to integrate it with their academic policies (Bordoloi et al., 2021). If they are able to form a curriculum appropriately to integrate mathematics learning into the blended learning system in their academics, it will create student learning satisfaction including improving their skills both in academic and non-academic environments (Abuhassna et al., 2020).

On the other hand, Rasheed et al. (2020) said, although the blended learning system offers various advantages, the success of this system is highly dependent on the knowledge they have. The knowledge possessed by students will allow them to integrate the mathematics learning system with the Blended learning method in their academic environment (Rasheed et al., 2020). This knowledge includes the skills they have to utilize technology in their mathematics learning system, especially in the blended learning method. Students who lack good technological skills will allow them to face obstacles in accessing and reducing their overall satisfaction with the mathematics learning process (Cihad, 2021).

In previous studies, it has been mentioned by Kang & Kim, (2021), Fisher et al. (2021), Fortin et al. (2019), Bervell & Umar (2020), Previtali & Scarozza (2019) who studied the effect of blended learning on student learning satisfaction in Australia, Singapore, Europe, and Italy. The results showed that blended learning significantly influenced the learning satisfaction of students in Australia, Singapore, Europe, and Italy. However, in Indonesia itself, research related to blended learning is still limited to character, attitude, environment, social factors, and also usage intentions (Mahmud, 2021; Suzianti & Paramadini, 2021; Syaiful Romadhon et al., 2019; Yulianti & Sulistiyawati, 2020). Moreover, Hoyles (2018) stated that the use of the blended learning method in mathematics learning is still in doubt. Therefore, the current researcher intends to further develop blended learning research by adopting student satisfaction factors in the mathematics learning system in Indonesia considering that there are still very few researchers who study these factors, especially in 2024.

Based on the statements previously mentioned by Rasheed et al. (2020) and Cihad (2021), where the success of using the blended learning method in the student environment depends on the knowledge and expertise they have. Therefore, the researcher also adopts knowledge and expertise as mediating factors to find out whether the existence of knowledge and attitudes will change the satisfaction of learning mathematics of students in Indonesia in adopting the blended learning method or not. This research is expected to be a reference for institutions in understanding the factors that influence student satisfaction in learning mathematics using blended learning in order to be able to adjust learning methods that are more appropriate to student needs, as well as encourage a more active academic environment in adopting technology in the teaching and learning process, especially in mathematics.

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 & Geiger, 2022; Metaferia et al., 2023). While the pandemic subsided in 2021, enabling the resumption of 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 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).

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 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 & 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., 2023).

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 & 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 (Sanusi, 2022; Mullen et al. 2023; Hill & Smith 2023; Awajan et al. 2024; Ali 2024; Kyei-Akuoko et al. 2025).

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., (2023), 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.

Literature Review

Blended Learning

According to Zagouras et al. (2022) blended learning is an educational system that combines face-to-face learning with independent online learning that involves the use of digital technology. This system is able to offer convenience in terms of time, place, and learning methods that allow someone to access materials more flexibly (Li et al., 2022). especially for students who are considered to have the highest level of busyness compared to other students, both activities in the academic environment and outside academic activities (Suzianti & Paramadini, 2021). Alkhatib (2018) stated that with the blended learning system, students not only get direct learning instructions through lecturers in class, but are also able to utilize digital resources such as videos, interactive modules, and online discussion forums including in mathematics learning. Students who are familiar with technology and independent learning will tend to be more satisfied because they are able to control their own learning pace (Li et al., 2022). This system also requires students to have a higher level of discipline and responsibility (Rasheed et al., 2020). With the right support from institutions and a good curriculum, the implementation of blended learning can improve the quality of experience and provide higher satisfaction for students (Sarkar et al., 2021).

As previously mentioned, blended learning can have an impact on student learning satisfaction. Students who are familiar with technology and independent learning tend to feel more satisfied because they can control their learning pace (Rasheed et al., 2020). On the other hand, students' knowledge of basic concepts greatly determines how effectively they can use blended learning (C. Li et al., 2019). Lazarevic & Bentz (2021) stated that students who have strong knowledge of the material being studied will be better able to access, understand, and apply information available online or face-to-face. This knowledge refers to students' expertise in using technology to support success in the blended learning system (Rasheed et al., 2020). Digital literacy, the ability to manage technological devices, and communication skills are very Students who have good technological skills will be more adaptable to the learning system. So that this is able to overcome challenges that may arise in the implementation of blended learning to significantly increase student learning satisfaction (Anthonysamy et al., 2020).

Blended Learning and Knowledge

According to Varadarajan (2020) Knowledge is defined as the accumulation of information, facts, skills, and understanding acquired by individuals through experience and education. In general, knowledge can be divided into two, namely declarative knowledge, knowledge of facts and concepts. Second, procedural knowledge, knowledge of how to do something (Demir et al., 2022). In education, knowledge is the main foundation for effective learning, including in mathematics courses. Blended learning that combines face-to-face learning methods with online learning has great potential to influence and enrich students' mathematical knowledge (Li et al., 2019). This model provides wider access to various digital information sources such as learning videos and discussion forums that support the enrichment of students' declarative knowledge (Alkhatib, 2018). In addition, the flexibility in blended learning allows students to organize their time and place of study according to their needs, and gives them the opportunity to explore the material independently (Li et al., 2022). Through learning that is accessed online, students not only learn mathematics from core concepts but are also involved in practical applications that strengthen their knowledge as a whole. In previous studies, it has been discussed as in the study of Li et al. (2019), where blended learning can effectively improve the knowledge of nursing students. They stated that blended learning can make it easier for nursing students to gain knowledge and complete learning tasks better. In line with the research of Kang & Kim (2021) which found that blended learning can improve the knowledge of students in Korea in public health courses. This is because students can access materials more easily and repeat difficult parts outside of class time to deepen their understanding. Turk et al. (2019) also stated that the existence of a blended learning system can influence the increase in knowledge in students. Because blended learning can minimize students from fatigue and increase their focus. Based on the findings above, the researcher hopes that:

H1: Blended Learning has a positive effect on student knowledge in mathematics learning in Indonesia.

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 discussions 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 (X. Li et al., 2022). Lazarevic & 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., 2023). 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

Burger et al. (2019) defines Skill as an individual's ability to perform certain tasks or jobs well and efficiently. Skills can be cognitive, technical, social, or managerial abilities that develop through learning and experience (Schallock et al., 2018). In the world of education, student skills include critical thinking skills, problem-solving, communication, and technical skills in the blended learning system in the application of learning mathematics (Coyne et al., 2018). Blended learning is able to provide students with opportunities to apply their knowledge in learning mathematics through online problem-based activities or case studies, thereby strengthening their critical thinking skills (Li et al., 2019). Charband & Jafari Navimipour (2016) stated that the integration of technology in the learning process also facilitates cross-geographic collaboration through online platforms. This encourages communication and teamwork skills in a broader context. Thus, blended learning not only provides flexibility but also creates a rich environment for developing students' skills in learning more essential mathematics.

In the research of Moradimokhles & Hwang (2022), it was found that the blended learning system was able to influence students' English language skills. They said that the blended learning system was able to provide a higher increase in students' English skills. In line with the research of Li et al. (2019) which found that blended learning can significantly improve the skills of nursing students. This is because blended learning is able to provide students with the flexibility to access materials according to their speed and learning style. Research by McCutcheon et al. (2018) also confirmed that blended learning was able to significantly influence skills in clinical supervisor learning. They argue that the blended learning method has a higher score because it has a higher level of efficiency. Based on the findings above, researchers hope that:

H2: Blended Learning has a positive effect on student skills in learning mathematics 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 & Borba, (2024) Further, 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 & Hwang, (2022) found that BL significantly improved students' English language skills. Li et al (2019) 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 as a key element in students' mathematics learning process is the foundation for the development of more complex skills (Kim et al., 2019). In an academic environment, knowledge influences the way they solve problems, make decisions, and develop skills to a professional level (Fengler & Taylor, 2019). The importance of knowledge lies in its ability to shape skills. Good knowledge allows students to understand mathematical concepts in depth and apply that understanding to practical situations (Lo Turco & Maggioni, 2022). Moreover, in modern education, the skills expected of students go beyond cognitive knowledge which are expected to have high problem-solving, critical thinking, and adaptation skills to dynamic changes in mathematics learning (Coyne et al., 2018).

In addition, knowledge allows students to access various perspectives that enrich critical and innovative thinking skills. So that knowledge is not only a passive tool, but an active resource that leads to innovative skills and effective problem solving (Franco & DeLuca, 2019). Murillo-Zamorano et al. (2019) in his research also stated that knowledge can significantly influence students' skills in using flipped classrooms. In line with the research of Alfiani et al. (2024), which states that there is a significant influence of knowledge on students' skills in listening and reading comprehension. The research of Murillo-Zamorano & Montanero (2018) also strengthens, Students' knowledge in terms of capacity has been shown to have an effect on improving oral presentation skills. Based on the findings above, the researcher hopes that:

H3: Knowledge has a positive effect on students' mathematics learning skills 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., 2024). 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., 2024).

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 (Franco & DeLuca, 2019). Research consistently demonstrates this relationship. (Murillo-Zamorano & Montanero, 2018) found that knowledge significantly influences students' skills in using flipped classrooms. Alfian et al. (2024) 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 as the main foundation that influences how students understand the material, especially in studying mathematics and applying it to various situations (Varadarajan, 2020). In studying mathematics, this knowledge does not only include facts and theories, but also the abilities needed to analyze information critically (Anderson et al., 2017). The more someone feels critical in knowing something, the more their satisfaction in studying mathematics will increase (Z. Sun et al., 2018). Student learning satisfaction as the level of pleasure and happiness felt by students towards their experience in studying mathematics, including students (Wong & Chapman, 2023). Learning satisfaction lies in how the knowledge they gain affects the overall learning experience (Murillo-Zamorano et al., 2019). Students who have in-depth knowledge of mathematics will be better able to accept the material being studied so that they feel more satisfied. Conversely, lack of knowledge will cause confusion, frustration, and decreased motivation which ultimately reduces their level of satisfaction in studying mathematics (Haghighat et al., 2023). Therefore, knowledge is a critical factor in creating a mathematics learning experience, especially for students to support more optimal academic achievement.~~

~~Previous studies have found that knowledge can influence learning satisfaction. Such as research conducted by Haghighat et al (2023) which found that knowledge can influence learning satisfaction in nursing students. In line with the findings of Murillo-Zamorano et al. (2019) who found that knowledge can significantly influence student learning satisfaction in using flipped classrooms. This is because academically students are required to study the material before face-to-face sessions as their main foundation for discussing in class. In the study (Waheed et al., 2016) it was also emphasized that the quality of knowledge can influence learning satisfaction in undergraduate and postgraduate students. Quality knowledge allows students to be more effective in achieving their academic goals. With these findings, the researcher hopes that:~~

~~H4: Knowledge has a positive effect on Mathematics Learning Satisfaction of students 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 & Montanero (2018) similarly observe that knowledge significantly influenced students' learning satisfaction in 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 are a person's abilities based on learning and experience that enable them to perform certain tasks effectively (Schallock et al., 2018). In studying mathematics in higher education, the skills possessed are the basis for how effectively students can absorb the material and apply it in real situations (Refdinal et al., 2023). Students who feel they have adequate skills tend to feel more confident which allows them to understand mathematics material in depth and bring out their self-satisfaction (Rajabalee & Santally, 2021). As in the study of Murillo-Zamorano et al. (2019), which states that students' expertise in using flipped classrooms can significantly affect student learning satisfaction. This is because students who have independent learning and time management skills tend to be better able to utilize the flipped classroom model. Lopes & Soares (2018) also showed that skills can increase learning satisfaction higher in the flipped classroom system. They consider flipped classrooms to have better efficiency in terms of time and place, so they can adjust their learning style. Based on previous findings, the researcher hopes that:

H5: Skill has a positive effect on Mathematics Learning Satisfaction of students in Indonesia.

Blended Learning and Knowledge and Learning Satisfaction

Blended learning as a learning method that combines face-to-face instruction with online learning provides more flexible knowledge in adjusting students' learning styles (Bordoloi et al., 2021). In supporting the mathematics learning process, the blended learning method allows them to access information independently and flexibly, thereby increasing their knowledge in depth. Wider blended learning access to materials also facilitates their mathematical exploration of subjects of interest (Islam et al., 2022). Better knowledge can strengthen conceptual understanding in applying the blended learning method and increase students' confidence in mastering mathematics material. When students feel that they have good mathematical knowledge in the application of blended learning, it will increase their learning satisfaction and study it continuously (Murillo-Zamorano et al., 2019).

As in the study of Li et al. (2019), where blended learning can effectively improve the knowledge of nursing students. Kang & Kim (2021) also found that blended learning can improve the knowledge of students in Korea in public health courses. Where blended learning is able to provide easier access to materials for students to repeat learning outside of class time. Kang & Kim (2021) also mentioned in their research that blended learning also affects the learning satisfaction of students in Korea in public health courses. On the other hand, research by Haghighat et al (2023) found that knowledge can affect learning satisfaction in nursing students. In line with the findings of Murillo-Zamorano et al. (2019), which states that knowledge can significantly affect student learning satisfaction in using flipped classrooms. The research of Murillo-Zamorano et al. (2019) also emphasized that flipped classrooms can influence student learning satisfaction mediated by knowledge. Based on the findings above, the researcher hopes that:

H6: Blended Learning has an effect on Student Mathematics Learning Satisfaction in Indonesia mediated by Knowledge..

Blended Learning and Skill and Learning Satisfaction

The development of expertise and technological skills is an aspect that is often encouraged through blended learning (Zagouras et al., 2022). By utilizing blended learning, students are trained to manage assignments and deadlines independently, thereby improving self-management skills, especially in mathematics learning which is considered to have a higher level of difficulty (Ndlovu & Mostert, 2018). As in the study of Moradimokhles & Hwang (2022) which states that blended learning can influence students' English language skills. In line with the research of McCutcheon et al. (2018) which states that blended learning can significantly influence skills in clinical supervisor learning. They said that learning through the blended learning method has a higher score because it has a better level of efficiency.

Research by Fisher et al. (2021) found that blended learning can influence student learning satisfaction at universities in Australia. With the blended learning method, students have the ability to access materials at any time and make it easier for them to adjust the learning process to their personal needs. On the other hand, expertise plays a very important role in supporting learning satisfaction. In the research of Murillo-Zamorano et al. (2019) it is explained that students' skills in using flipped classrooms can significantly influence students' learning satisfaction. Lopes & Soares (2018) also showed that skills can increase learning satisfaction higher in the flipped classroom system. Based on the findings above, the researcher hopes that:

H7: Blended Learning has an effect on students' mathematics Learning Satisfaction in Indonesia mediated by Skill.

Blended Learning and Knowledge and Skill

Blended learning that combines face-to-face instruction with online learning elements allows flexibility in improving student knowledge and interacting with fellow users (Alkhatib, 2018). In the process of learning mathematics, blended learning provides an opportunity for students to learn basic concepts independently through digital resources, and use face-to-face sessions to deepen their understanding of more complex ones (Martínez et al., 2020). The knowledge gained through independent learning not only helps students understand the theory, but also builds analytical and problem-solving skills that are essential in their mathematics learning. Such as research conducted by Li et al. (2019), where blended learning can effectively improve the knowledge of nursing students. Kang & Kim (2021) also mentioned that blended learning can provide easier access to materials for students to repeat learning in difficult parts outside of class time to deepen their understanding.

Research by Li et al. (2019) stated that blended learning can influence students' skills in studying nursing education. This is because the flexibility provided by blended learning allows them to learn according to their rhythm and needs, as well as direct supervision from lecturers face to face to help them perfect their practical skills. In addition, research by Murillo-Zamorano et al. (2019) found that knowledge can significantly influence students' skills in using flipped classrooms. The findings of Alfiani et al. (2024) also clarify that knowledge can influence students' listening and reading skills. Based on the findings above, researchers hope that:

H8: Blended Learning has an effect on students' mathematics learning skills in Indonesia through the mediation of Knowledge.

Knowledge and Skill and Learning Satisfaction

Knowledge is the main foundation in the learning process, especially in complex disciplines such as mathematics (Carrillo-Yañez et al., 2018). Knowledge allows students not only to understand the theory but also to utilize their skills in solving more challenging mathematical problems (Masingila et al., 2018). Strong knowledge will strengthen students' skills, which in turn will contribute to students' level of learning satisfaction. Students with good knowledge tend to develop more effective skills, which directly improve their learning process (Kim et al., 2019). So that the existence of knowledge and skills will facilitate students' mathematics learning that is more meaningful and has a higher level of learning satisfaction (Murillo-Zamorano et al., 2019).

Like the research conducted by Alfiani et al. (2024) which states that there is a significant influence of knowledge on students' skills in listening and reading comprehension. In line with the findings of Murillo-Zamorano & Montanero (2018), where students' knowledge in terms of capacity has been shown to have an effect on improving oral presentation skills. When students have good knowledge, they tend to be more confident in conveying information and are able to communicate their ideas in a structured manner. Haghighat et al (2023) also found that knowledge can influence learning satisfaction in nursing students. Knowledge is a critical factor in creating a mathematics learning experience, especially for students to support more optimal academic achievement. On the other hand, Murillo-Zamorano et al. (2019) explained that students' expertise in using flipped classrooms can significantly influence students' learning satisfaction. This is because students who are skilled in utilizing the flipped classroom method tend to be more prepared to face face-to-face sessions, because they have a basic understanding through independent learning. Lopes & Soares (2018) also strengthens, where skills can increase learning satisfaction higher in the flipped classroom system. Based on the findings above, the researcher hopes that:

H9: Knowledge influences the Learning Satisfaction of mathematics students in Indonesia through Skill mediation.

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 & 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 & 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 & 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 & Kang (2025) also noted that BL directly influenced learning satisfaction for these students. Furthermore, Roos & Bagger (2024) confirmed that knowledge impacts learning satisfaction in nursing students. Murillo-Zamorano & Montanero (2018) reinforced this by finding that knowledge significantly affected student learning satisfaction in flipped classrooms. Critically, Sojayapan & Khlaisang (2020) 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 & 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 & 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., 2023). 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 & 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 & 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 & Mede (2021) found that knowledge significantly influenced students' skills in using flipped classrooms. Hankeln & 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 & Montanero (2018) the study explained that students' expertise in the flipped classroom significantly influenced their learning satisfaction, as skilled students are better prepared for face-to-face sessions due to their foundational independent learning. Shlomo & Rosenberg-Kima (2024) also reinforced that skills lead to higher learning satisfaction in the 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.

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~~**Research Methodology**~~

~~Data collection in this study was conducted using quantitative survey techniques. This survey was distributed to university students in Indonesia who had been involved in Blended Learning-based mathematics learning. Respondents were selected using the snowball sampling method, where initial respondents were recruited based on social networks, who then recommended other relevant respondents. This technique was used because it is difficult to reach a wider population directly. On the other hand, the success and efficiency of the snowball sampling approach depend almost entirely on the personal or professional contacts of the researcher (Rahman, 2023). The questionnaire used consisted of several parts, including questions about the demographics of respondents (such as age, gender, and education level) as well as questions related to their experiences in using the Blended Learning method for mathematics learning. This survey was conducted online to ensure wider reach and ease of access for respondents. The number of samples collected and eligible for analysis in this study was 304 students based on gender, education level, gadgets used in learning on several islands in Indonesia (See Table 1).~~

~~The variables measured in this study include Blended Learning, Knowledge, Skill, and Learning Satisfaction. Each variable is measured using a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree) to assess respondents' perceptions of the various aspects studied. The following is a description of each variable:~~

~~1. Blended Learning (BL): Measured by adapting items that assess the effectiveness of using Blended Learning in learning, time flexibility, ease of access to materials, and integration of~~

online and face-to-face learning. BL measurement uses several previous studies adopted and adapted by Birbal et al. (2018) & Yehia et al. (2022).

2. Knowledge (KN): Measures how well students understand mathematical concepts through Blended Learning. Questions include assessments of conceptual understanding, clarity of the material presented, and ability to apply theory. KN measurement uses several previous studies adopted and adapted by Murillo-Zamorano et al. (2019)

3. Skill (SK): Measures students' skills in solving mathematical problems and using tools provided through the Blended Learning platform. Related items include analytical skills, problem solving, and application of knowledge in practical situations. SK measurement uses several previous studies adopted and adapted by Murillo-Zamorano et al. (2019)

4. Learning Satisfaction (LS): Measured by items that assess students' overall satisfaction with their learning experience, including satisfaction with the Blended Learning method, lecturers' teaching ability, and satisfaction with increasing knowledge and skills. The KN measurement uses several previous studies adopted and adapted by Huang (2021) & P. C. Sun et al. (2008)

Data analysis in this study was carried out using the Structural Equation Model – Partial Least Square (SEM-PLS) method, which was implemented in two main stages according to the recommendations of Hair et al. (2022), Henseler et al. (2016) and Rigdon et al. (2017). The first stage in SEM-PLS is the Evaluation of the Measurement Model to ensure the reliability and construct validity of the research variables, including Blended Learning, Knowledge, Skill, and Learning Satisfaction. This step is important to ensure that each construct is measured consistently and accurately. After the measurement model is evaluated and meets the reliability and validity requirements, the second step is the Evaluation of the Structural Model to test the relationship between the latent variables that have been identified. At this stage, path analysis is carried out to test the hypothesis regarding the direct and indirect effects between variables. To test the significance of the direct and indirect paths, the bootstrap resampling technique with 5000 samples was used. This approach allows for a more robust standard error distribution, providing a more accurate estimate of the significance of the effect between variables.

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 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 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).

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).

Table 1. Demographic Respondents

Variable	Demographic	Count	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

The core variables measured in this study included Blended Learning (BL), Knowledge (KN), Skill (SK), 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 dimensions 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 context, encompassing aspects such as time flexibility, ease of material access, and the seamless 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 & 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 items were adapted from previous studies by Huang, (2021) and Sun et al. (2008).

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, which is beneficial for data collected via Likert scales (Hair et al., 2023; Henseler et al., 2016). The analysis 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).

The initial stage involved the **Evaluation of the Measurement Model,** which was crucial for establishing 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. Specifically, **reliability** was assessed through internal consistency using **Cronbach's Alpha** (α) and **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 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).

Following the successful validation of the measurement model, the subsequent stage involved evaluating **the Structural Model.** This phase focused on testing the hypothesised relationships between the 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.

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Result and Discussion

Results and discussions

This section presents the findings derived from the statistical analysis, specifically focusing on the evaluation of the measurement model and the structural model. We detail the outcomes of our investigation into the hypothesized relationships between the identified laten variables, followed by a comprehensive disscussion that interpretes these results in the context of existing literature and their implication for mathematics education.

~~**Uji *Measurement Model (Outer Model)***~~

~~Hair et al. (2022) stated that before conducting hypothesis testing in this study, a Measurement Model test was conducted which included indicator reliability, internal consistency reliability, convergent validity and discriminant validity. The indicator reliability test is used to measure how much variance each indicator is explained by its construct, which shows the reliability of the indicator by looking at the outer loading value. The recommended outer loading value is > 0.70. It can be seen in table 2, the outer loading in this study has reached > 0.70 which indicates that the indicator reliability in this study has been met. Table 2 shows the Cronbach's alpha and composite reliability values used in measuring internal consistency reliability to determine the extent to which indicators that measure the same construct are related to each other. Table 2 shows the Cronbach's alpha and composite reliability values are > 0.70, so the indicators used in this study can be declared reliable as recommended by Hair et al. (2022).~~

~~In the convergent validity test, the average variance extracted (AVE) value is used to see higher loads in a narrow range which indicates that all items can explain their latent constructs. Manley et al. (2021) stated that the recommended AVE value is at 0.05. In table 2, the AVE value in this study has been > 0.50 so that the convergent validity in this study has been met. Discriminant validity is used to see how much a construct is empirically different from other constructs in the structural model. Henseler et al. (2015) recommend the heterotrait-monotrait ratio (HTMT) for better measurement with a threshold value of 0.90. Based on table 3, the HTMT value is below 0.90, which indicates that discriminant validity has been met and can be used for further analysis.~~

~~Table 2. Outer loading and Convergent Validity~~

~~Variable~~	~~Item~~	~~OL~~	~~α~~	~~CR~~	~~AVE~~
~~Knowladge~~	~~KNO1~~	~~0,924~~	~~0,795~~	~~0,907~~	~~0,829~~
~~-~~	~~KNO2~~	~~0,897~~	~~-~~	~~-~~	~~-~~
~~Blended Learning~~	~~Online Learning~~	~~0,789~~	~~0,834~~	~~0,877~~	~~0,508~~

-	Learning Flexibility	0,903	-	-	-
Learning Flexibility	LF1	0,740	-	-	-
-	LF2	0,853	-	-	-
-	LF3	0,827	-	-	-
Online Learning	OL1	0,735	-	-	-
-	OL2	0,872	-	-	-
-	OL3	0,888	-	-	-
-	OL4	0,888	-	-	-
Learning Satisfaction	LS1	0,821	0,938	0,951	0,766
-	LS2	0,839	-	-	-
-	LS3	0,906	-	-	-
-	LS4	0,924	-	-	-
-	LS5	0,889	-	-	-
-	LS6	0,867	-	-	-
Skill	SKI1	0,856	0,916	0,935	0,706
-	SKI2	0,867	-	-	-
-	SKI3	0,736	-	-	-
-	SKI4	0,833	-	-	-
-	SKI5	0,880	-	-	-
-	SKI6	0,860	-	-	-

Table 3. Discriminant Validity

	Blended Learning	Knowladge	Learning Satisfaction	Skill
Blended Learning	-	-	-	-
Knowladge	0,400	-	-	-
Learning Satisfaction	0,477	0,785	-	-
Skill	0,526	0,827	0,705	-

Uji *Structural Model*

After evaluating the research model, the next step is to test the hypothesis on the constructs studied in the Structural Model test which includes Indicator Collinearity (VIF), Path Coefficients, Coefficient of determination (R2), and Effect size (f2). First of all, before testing the hypothesis on the Path Coefficients, a test was carried out on the Indicator Collinearity to ensure that there were no collinearity problems between the constructs studied. Becker et al. (2015) suggested a recommended VIF threshold of <5. Table 4 shows that the VIF values for the paths range from 1,000 to 2,003, well below the threshold of 5. This confirms that there is no issue of multicollinearity among the constructs, ensuring the stability of the regression coefficients. To test the hypothesis on the constructs studied, bootstrapping was carried out by 5000 resamples with a bootstrap confidence level of 95% as suggested by Henseler et al. (2016). It can be seen in table 4, Blended Learning on Knowledge (β = 0.329, T-stat = 5.529) is positive and significant, indicating that the implementation of blended learning strategies positively improves students' knowledge. This can be concluded to accept H1. The findings of this study indicate that Blended

Learning has a significant effect on improving students' knowledge. This is in line with the research of Li et al. (2019) which shows that Blended Learning provides easier access for students to repeat difficult material, which ultimately improves their understanding of complex mathematical concepts. In addition, Blended Learning allows students to learn at their own pace, which is very important in learning mathematics, because this subject often requires extra time to understand abstract concepts and requires repetition of material. With wider access to digital resources, such as learning videos and interactive modules, students can explore various ways to understand difficult mathematical concepts. For example, research by Bordoloi et al. (2021) states that the Blended Learning method is able to increase student engagement and motivation to study challenging topics, such as mathematics, because this method provides flexibility in learning styles. This is consistent with research findings showing that knowledge gained through Blended Learning includes not only theoretical understanding but also the ability to apply these concepts in a broader context.

The effect of Blended Learning on Skills (β = 0.252, T-stat = 6.032) is also positive and significant. It can be concluded that H2 is accepted. Burger et al. (2019) emphasized the importance of skills in technology-based learning, where Blended Learning allows students to hone the technical and analytical skills needed to solve mathematical problems. The use of technology in the learning process, such as online discussion forums and computer-based practice questions, provides opportunities for students to practice and apply mathematical knowledge in real situations. This finding is in line with research by McCutcheon et al. (2018), which shows that Blended Learning provides a significant increase in students' skills, because this method allows them to learn independently and apply relevant skills in various situations. In the context of mathematics learning, students are faced with the challenge of understanding and solving complex problems. The use of Blended Learning helps them practice problem-solving skills more effectively, because students can access the material at any time and repeat the exercises as needed.

Knowledge on Learning Satisfaction (β = 0.442, T-stat = 7.186) shows a strong positive relationship, indicating that students who gain greater knowledge feel more satisfied with their learning experience. Thus accepting H3. The knowledge gained during the learning process has a significant direct effect on learning satisfaction. This indicates that students who feel they have gained adequate knowledge tend to be more satisfied with their learning experience. This finding is consistent with the research of Murillo-Zamorano et al. (2019), which shows that increased knowledge during the learning process contributes to higher learning satisfaction, especially when students feel that they can apply the knowledge they have gained in practical contexts. In mathematics learning, learning satisfaction is often related to how well students understand the concepts taught and their ability to solve the problems faced. When students feel that they gain a deep understanding of mathematics topics through Blended Learning, their satisfaction with the learning process increases, because they feel more prepared and confident in facing academic challenges.

Similarly, Knowledge to Skills (β = 0.625, T-stat = 14.792) showed a very strong effect, indicating that higher knowledge significantly improves students' skills. It can be concluded to accept H4. This finding is in line with the concept that good knowledge is the foundation for developing higher skills, especially in complex subjects such as mathematics. In mathematics learning, in-depth knowledge of theoretical concepts provides a strong foundation for students to apply this understanding in practical contexts, such as problem solving and analysis. According to Li et al. (2019), the knowledge gained through Blended Learning allows students to improve their

~~problem-solving skills because they can access various digital resources that help them understand concepts more deeply. With a strong understanding of theory, students are better prepared to apply their knowledge in real situations, so their critical and analytical thinking skills also improve.~~

~~Knowledge not only helps students understand the subject matter but also shapes their ability to apply mathematical concepts to practical contexts. Demir et al. (2022) highlighted that declarative knowledge (knowledge of facts and concepts) is often the basis for the development of procedural skills (how to do something), which are important in mathematics learning. Students who have strong declarative knowledge will be better able to develop procedural skills, such as the ability to solve equations or solve complex mathematical problems. Burger et al. (2019) also showed that in-depth knowledge facilitates the development of more sophisticated skills, such as critical thinking and problem-solving skills. In the context of Blended Learning, students can utilize various materials available online to strengthen their knowledge and then apply that knowledge in practice questions or discussions that require high-level problem-solving skills.~~

~~Skills to Learning Satisfaction (β = 0.342, T-stat = 4.985) also has a significant positive effect, meaning that students who acquire better skills tend to be more satisfied with their learning outcomes. Thus, H5 is accepted. This study also found that the skills acquired during learning contributed significantly to students' learning satisfaction. Lopes & Soares (2018) stated that students who have better skills in using learning technology tend to be more satisfied with their learning process, especially because they feel more capable of solving problems and managing independent learning. In the context of mathematics learning, skills developed through Blended Learning, such as analytical and problem-solving skills, provide students with greater self-confidence, which ultimately increases their satisfaction.~~

~~Students who feel they have developed skills relevant to mathematics learning, such as critical and analytical thinking skills, tend to be more satisfied because they are able to see practical applications of the knowledge they have acquired. This finding is also supported by research by Rajabalee & Santally (2021), which states that skills developed through technology-based learning significantly increase student satisfaction, because they feel more prepared to face challenges in the real world.~~

~~The indirect effect of Blended Learning on Learning Satisfaction through Knowledge (β = 0.145, T-stat = 4.272) is significant. Thus, H6 is accepted. This mediation effect highlights the important role of skills in bridging the relationship between Blended Learning and student learning satisfaction, especially in mathematics learning. Blended Learning, with an approach that combines online and face-to-face learning, provides students with the opportunity to develop better problem-solving skills. In the context of mathematics learning, these skills are very important because students are often faced with questions that require in-depth analysis and application of theory to real situations. Blended Learning, with the provision of online materials such as interactive exercises and simulations, provides space for students to practice and deepen their understanding independently.~~

The skills acquired through the Blended Learning method then have a positive impact on student learning satisfaction. Rajabalee & Santally (2021) found that students who feel skilled in using learning technology and are able to solve academic problems more effectively tend to be more satisfied with their learning experience. This also applies to mathematics learning, where students who feel more skilled in solving math problems tend to feel more confident and satisfied with the learning process. In addition, the skills developed through Blended Learning not only include technical skills in using math tools, but also include critical thinking and logical skills, which are very important in solving math problems. McCutcheon et al. (2018) stated that Blended Learning encourages students to think independently and apply critical thinking skills in practical situations. This is very relevant in the context of mathematics learning, where students are often faced with complex problems that require a systematic and logic-based approach.

Another indirect relationship is Blended Learning to Skills through Knowledge ($\beta = 0.206$, T-stat = 5.290), indicating that knowledge acts as a mediator between blended learning and skill development. It can be concluded that H7 is accepted. Knowledge acts as a strong mediator in the relationship between Blended Learning and Skills. As highlighted in the study by Burger et al. (2019), good theoretical knowledge often forms a solid foundation for the development of practical skills. In the context of mathematics learning, students who have a deep understanding of mathematical theories tend to be better able to apply this knowledge in solving real problems, which improves their skills. Blended Learning provides students with the opportunity to learn mathematical theories in various formats (text, video, interactive exercises), allowing them to learn in a way that best suits their learning style. The knowledge gained from this method then allows students to develop better skills in solving mathematical problems, both in the classroom and in real-life contexts. McCutcheon et al. (2018) found that knowledge gained through online learning contributed significantly to the development of practical skills in areas requiring deep conceptual understanding, including mathematics.

The mediation of Blended Learning on Learning Satisfaction through Skills ($\beta = 0.086$, T-stat = 3.669) is significant, although with a smaller effect. Thus accepting H8. Blended Learning indirectly contributes to learning satisfaction through skill development. As found in this study, better skills provide students with higher self-confidence, which in turn increases their satisfaction with the learning experience. Rajabalee & Santally (2021) showed that students who feel skilled in using learning technology and applying mathematical concepts tend to be more satisfied with their learning process. In mathematics learning, skills developed through Blended Learning, such as the ability to solve problems or use mathematical technology (e.g., graphing calculators, modeling software), play an important role in increasing students' self-confidence. The more skilled students are in utilizing these tools, the more satisfied they are with their learning outcomes. This indirect effect shows that Blended Learning not only provides direct benefits in improving skills but also helps increase students' learning satisfaction through the development of these skills.

The final mediation effect of Knowledge on Learning Satisfaction through Skills ($\beta = 0.214$, T-stat = 4.777) indicates that skills act as a mediator between knowledge and satisfaction. It is concluded that H9 is accepted. Students who have a deep understanding of mathematical concepts are more likely to be able to apply their knowledge in practical situations, leading to better skill development. Demir et al. (2022) found that declarative knowledge (theoretical knowledge) often acts as an important foundation for the development of procedural skills (practical application). In mathematics learning, strong theoretical knowledge helps students develop better analytical and problem-solving skills, which ultimately increases their learning

~~satisfaction. In the context of Blended Learning, the knowledge gained through various online resources allows students to practice and strengthen their skills in solving mathematical problems. These skills not only help students achieve better academic results but also increase their satisfaction with the learning process, as they feel more prepared and able to overcome academic challenges.~~

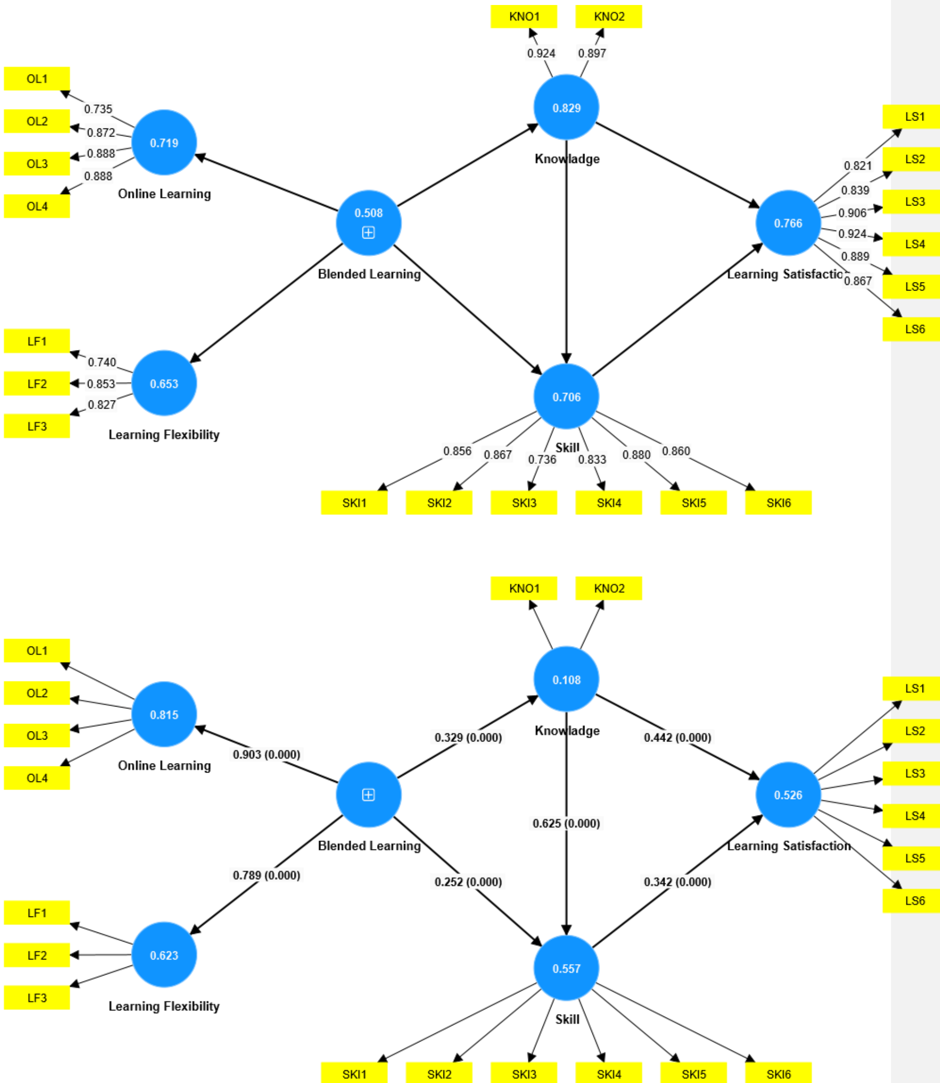

Figure 1. Outer and Inner Model

The coefficient of determination (R2) is used to measure the extent to which exogenous constructs can explain endogenous constructs in research. Hair et al. (2022) stated that R2 values of 0.25, 0.50, and 0.75 indicate weak, moderate, and strong levels. In table 5, R^2 Adjusted shows that this research model is able to explain the variation in Learning Satisfaction by 52.3%, and the variation in Skill by 55.4%. This shows that the knowledge and skills acquired through Blended Learning directly affect student learning satisfaction at a moderate level. Effect size (f2) is used in SEM testing to measure exogenous constructs in explaining endogenous constructs by recalculating R2 by eliminating one exogenous construct at a time (Hair et al., 2022). At an effect size of 0.02 it is stated to have a small effect, 0.15 is stated to be moderate and 0.35 is stated to be large (Cohen, 1988). For example, the effect of Knowledge on Skills ($f^2 = 0.786$) is very large, indicating that knowledge greatly contributes to skill development. Other relationships, such as Knowledge on Learning Satisfaction ($f^2 = 0.206$), also show moderate effects, further emphasizing the importance of knowledge acquisition in shaping positive learning outcomes.

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	-	-

Table 5. Coefficient of Determination

-	R-square	Adjusted R-square
Knowladge	0,108	0,106
Learning Satisfaction	0,526	0,523
Skill	0,557	0,554

Evaluation Measurement Model

Before proceeding with hypothesis testing, a rigorous evaluation of the measurement model was conducted to establish the reliability and validity of all constructs. This critical step encompassed assessments 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 below 0.90. This outcome unequivocally indicates that discriminant validity has been established for all constructs, rendering them suitable for subsequent analysis within the structural model.

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	Online Learning	0,789	0,834	0,877	0,508
Learning	Learning Flexibility	0,903			
Learning	LF 1	0,740			
Flexibility	LF 2	0,853			
	LF 3	0,827			
Online	OL 1	0,735			
Learning	OL 2	0,872			
	OL 3	0,888			
	OL 4	0888			
Learning	LS 1	0,821	0,938	0,951	0,766
Satisfaction	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:

	Blended Learning	Knowledge	Learning Satisfaction	Skill
Blended Learning				
Knowledge	0,400			
Learning Satisfaction	0,477	0,785		
Skill	0,526	0,827	0,705	

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% 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.

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 students' 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 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.

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 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 invaluable opportunities for students to practice and apply their mathematical knowledge in practical situations actively. This finding resonates strongly with Dwi Lestari & 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 & 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 the 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 & 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 & 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.

Table 4: Path Coefficients, Effect Size, and Collinearity Test

	ß	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	-	-

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. (2022) 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 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.

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

Effect Size (f2)

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). Y. Li (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.

Potential Causes for Variations from Related Studies

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.

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 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.

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Conclussion

~~This study aims to analyze the effect of Blended Learning on students' Learning Satisfaction in mathematics learning, by considering the role of Knowledge and Skill as mediators. This study aims to explore how Blended Learning can improve students' knowledge and skills, which ultimately affect their level of satisfaction in the learning process. The results of the analysis show that Blended Learning has a significant direct effect on students' Knowledge and Skill. Blended Learning allows students to access materials more flexibly and deeply, which contributes to an increase in understanding of mathematical concepts. This knowledge then has a direct impact on improving students' skills in solving mathematical problems. In addition, the skills acquired by~~

students also directly increase their Learning Satisfaction, because students feel more confident and able to face academic challenges. The results of the analysis show that Blended Learning has a significant direct effect on students' Knowledge and Skill. Blended Learning allows students to access materials more flexibly and deeply, which contributes to an increase in understanding of mathematical concepts. This knowledge then has a direct impact on improving students' skills in solving mathematical problems. In addition, the skills acquired by students also directly increase their Learning Satisfaction, because students feel more confident and able to face academic challenges.

These findings have important implications for educational institutions, especially in mathematics teaching. Blended Learning has proven effective in improving student learning outcomes, so the application of this method needs to be expanded and deepened in the higher education curriculum. Institutions need to provide more interactive content, digital learning aids, and adequate technological support so that students can optimally utilize the Blended Learning method. In addition, training for lecturers to integrate Blended Learning more effectively is also needed so that the learning process becomes more dynamic and relevant to student needs. This study has several limitations that need to be considered. First, the sampling technique used, such as snowball sampling, can limit the generalizability of the findings because the resulting sample may not be fully representative of the wider student population. Second, this study used a cross-sectional design, which only captures the relationship between variables at one point in time. As a result, changes in behavior or long-term effects of Blended Learning on learning satisfaction cannot be clearly identified.

For future research, it is recommended to use a longitudinal design to measure changes in student attitudes and behavior over time in the context of Blended Learning. In addition, further research can use more diverse and representative sampling techniques so that the results can be more generalized. Future research can also explore other variables such as self-regulation, technology acceptance, or learning engagement as factors that can influence the success of Blended Learning in increasing student learning satisfaction.

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.

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 of our findings, as the resulting sample may not be fully representative of the diverse student population across Indonesia. Second, adopting a cross-sectional design restricts our ability to capture dynamic 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 learning engagement, as potential factors that contribute to the success of BL in fostering student learning satisfaction.

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Please accept my sincere apologies for the delay in submitting this review. I took the time to carefully and thoroughly evaluate the revised manuscript entitled “The Impact of Blended Learning on Knowledge, Skills, and Satisfaction in Mathematics: A Study in Indonesian Universities.” The delay was due to my commitment to ensuring a meticulous review of the revisions made by the authors.

Having examined the manuscript in detail, I can confirm that the authors have addressed all of my previous concerns in a satisfactory manner. The revisions have substantially improved the quality of the paper. The structure is now clearer, the methodology more robust, and the discussion more insightful and well-grounded in relevant literature. The study’s contribution to the field of mathematics education, particularly within the Indonesian higher education context, is now articulated more convincingly.

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The impact of blended learning on knowledge, skills and satisfaction in mathematics: a study in Indonesian universities AQ1

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Abstract

AQ2 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 learning on students' knowledge, skills and learning satisfaction in mathematics. This study focuses on mathematics learning specifically at the university level. A survey was conducted on 304 Indonesian university students engaged in blended learning 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 optimising curriculum design in higher education to enhance the implementation of blended learning and improve the quality of mathematics learning, particularly by highlighting effective teaching methods within this modality.

KEYWORDS

Blended learning; knowledge; Skill; learning satisfaction; higher education mathematics education; Structural equation model

SUBJECTS

Social Sciences; Education; Higher Education; Study of Higher Education;Teaching & Learning

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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 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.

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 & Geiger, 2022; Metaferia et al., 2023). While the pandemic subsided in 2021, enabling the resumption of 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 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).

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 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. (2019) [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 (Franco & DeLuca, 2019) [delete.]. Research consistently demonstrates this relationship. Murillo-Zamorano and Montanero (2018) found that knowledge significantly influences students' skills in using flipped classrooms. Alfian et al. (2024) [delete reference] 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 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 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.

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 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 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).

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).

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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

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The core variables measured in this study included Blended Learning (BL), Knowledge (KN), Skill (SK) 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 dimensions 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 context, encompassing aspects such as time flexibility, ease of material access and the seamless 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 items were adapted from previous studies by Huang (2021) and Sun et al. (2008).

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, which is beneficial for data collected via Likert scales (Hair et al., 2023; Henseler et al., 2016). The analysis 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).

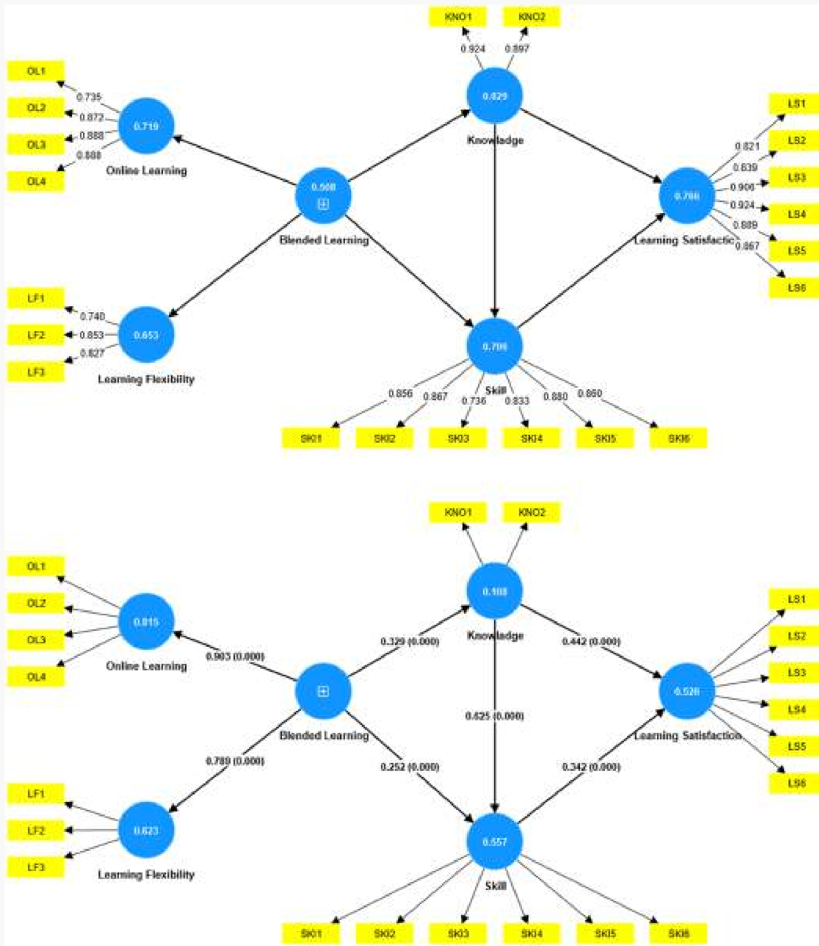
The initial stage involved the Evaluation of the Measurement Model, which was crucial for establishing the reliability and construct validity of research variables: Blended Learning, Knowledge, Skill and Learning Satisfaction. This phase ensured that each construct was consistently and accurately measured. Specifically, reliability was assessed through internal consistency using Cronbach's Alpha (α) and 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 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).

Following the successful validation of the measurement model, the subsequent stage involved evaluating the Structural Model. This phase focused on testing the hypothesised relationships between the 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.

Results and discussions

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

Figure 1. Outer and inner model.



Evaluation measurement model

Before proceeding with hypothesis testing, a rigorous evaluation of the measurement model was conducted to establish the reliability and validity of all constructs. This critical step encompassed assessments 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.

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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.

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

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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	

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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% 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.

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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	–	–

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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 students' 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 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.

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 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 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 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.

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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

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Effect size (f2)

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.

Potential causes for variations from related studies

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.

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 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.

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 of our findings, as the resulting sample may not be fully representative of the diverse student population across Indonesia. Second, adopting a cross-sectional design restricts our ability to capture dynamic 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 learning engagement, as potential factors that contribute to the success of BL in fostering student learning satisfaction.

Disclosure statement

No potential conflict of interest was reported by the authors.AQ4

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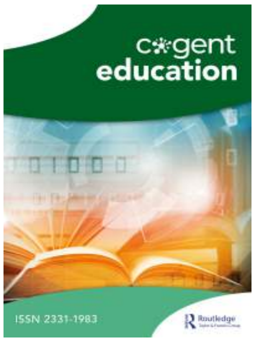

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The impact of blended learning on knowledge, skills and satisfaction in mathematics: a study in Indonesian universities

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ABSTRACT
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 learning on students' knowledge, skills and learning satisfaction in mathematics. This study focuses on mathematics learning specifically at the university level. A survey was conducted on 304 Indonesian university students engaged in blended learning 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 optimising curriculum design in higher education to enhance the implementation of blended learning and improve the quality of mathematics learning, particularly by highlighting effective teaching methods within this modality.

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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 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.

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 & Geiger, 2022; Metaferia et al., 2023). While the pandemic subsided in 2021, enabling the resumption of 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 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).

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

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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 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 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.

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 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 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).

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) 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 dimensions 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 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

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 items were adapted from previous studies by Huang (2021) and Sun et al. (2008).

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, which is beneficial for data collected via Likert scales (Hair et al., 2023; Henseler et al., 2016). The analysis 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).

The initial stage involved the Evaluation of the Measurement Model, which was crucial for establishing 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. Specifically, reliability was assessed through internal consistency using Cronbach's Alpha (α) and 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 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).

Following the successful validation of the measurement model, the subsequent stage involved evaluating the Structural Model. This phase focused on testing the hypothesised relationships between the 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.

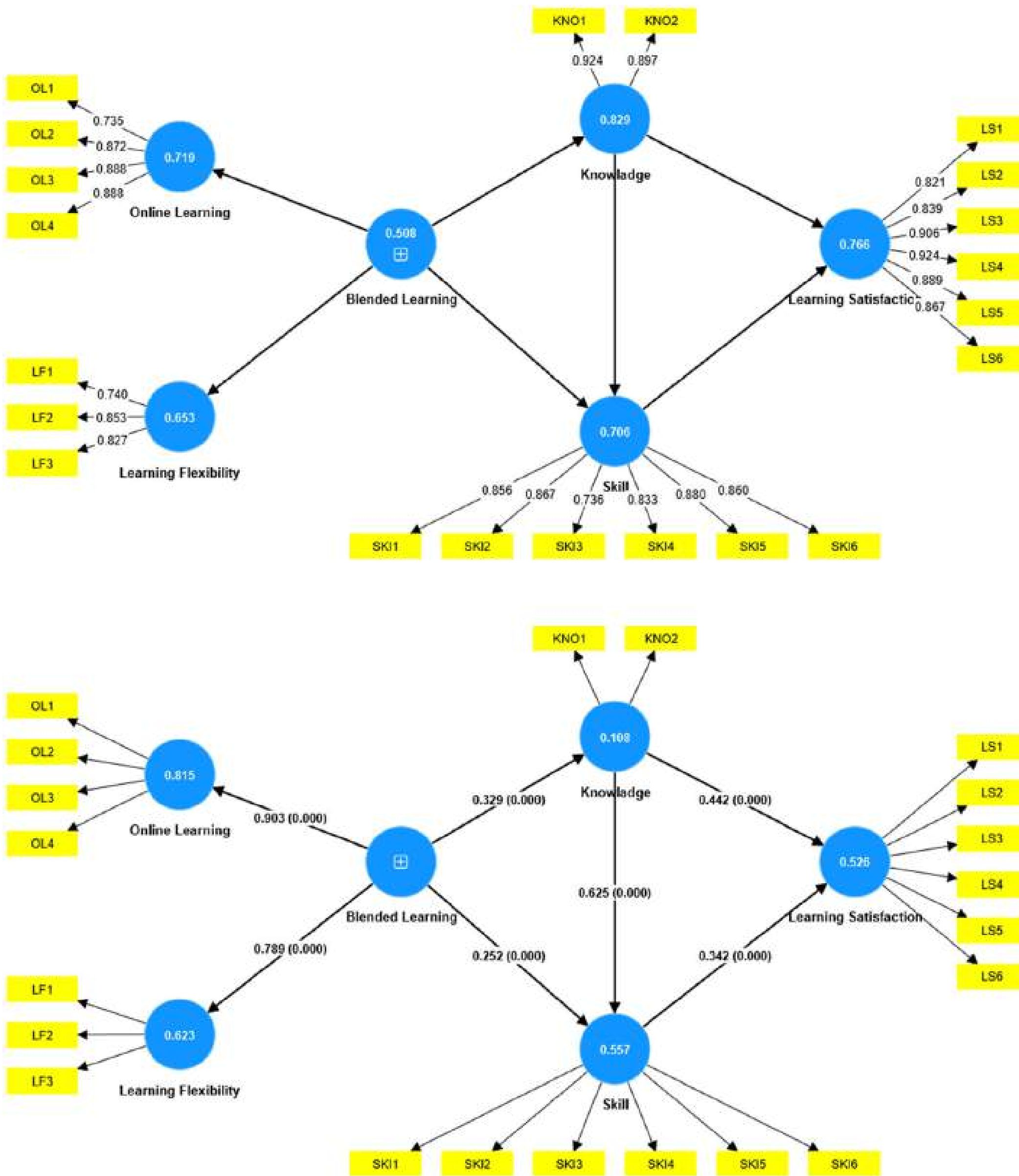

Figure 1. Outer and inner model.

Results and discussions

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

Evaluation measurement model

Before proceeding with hypothesis testing, a rigorous evaluation of the measurement model was conducted to establish the reliability and validity of all constructs. This critical step encompassed assessments 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	–	–

below 0.90. This outcome unequivocally indicates that discriminant validity has been established for all 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% 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.

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 students' 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 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.

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 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 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

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

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)

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.

Potential causes for variations from related studies

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.

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 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.

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 of our findings, as the resulting sample may not be fully representative of the diverse student population across Indonesia. Second, adopting a cross-sectional design restricts our ability to capture dynamic 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 learning engagement, as potential factors that contribute to the success of BL in fostering student learning satisfaction.

Disclosure statement

No potential conflict of interest was reported by the authors.

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