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Utilizing TPACK to Mitigate Learning Loss in Junior High Schools: An Empirical Study from Riau Province, Indonesia

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ABSTRACT

The COVID-19 pandemic has caused significant learning loss among Indonesian students, particularly at the junior secondary level. This disruption highlights the urgent need for effective strategies to restore educational quality. The Technological Pedagogical Content Knowledge (TPACK) framework offers a promising approach for integrating technology into teaching to mitigate such losses. This study involved 719 junior high school teachers from Riau Province, selected through stratified random sampling. Data were collected using a validated questionnaire measuring teachers' TPACK competence, technology utilization, and efforts to mitigate learning loss. Descriptive and inferential statistical analyses were conducted using SPSS, including path and correlation analyses. The findings reveal that both the construction and utilization of TPACK-based ICT significantly contributed to reducing learning loss, with a combined influence of 88.7%. Teachers with strong TPACK competencies demonstrated greater effectiveness in implementing technology-enhanced learning. However, challenges such as low digital literacy and unequal access to infrastructure remain significant barriers. These results underscore the strategic role of teacher competence and infrastructure readiness in addressing post-pandemic learning gaps. The strong correlation between TPACK use and learning loss mitigation suggests that targeted professional development and digital transformation policies are essential. Improving TPACK competence among educators and enhancing digital infrastructure are critical to mitigating learning loss. The study advocates for national policies that institutionalize TPACK-based training and equitable technology access to promote pedagogical innovation and reduce educational disparities.

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1. INTRODUCTION

The global education landscape has undergone massive disruption in recent years, particularly due to the COVID-19 pandemic that forced school closures and the abrupt transition to distance learning (Durrani & Ozawa, 2024). According to Kuzmanic et al (2024), more than 1.6 billion students worldwide have learning disabilities, exacerbating existing educational inequalities. Although schools have reopened, many students face learning loss—a decline in academic achievement due to prolonged learning gaps (Harmey & Moss, 2023). This phenomenon is particularly pronounced in developing countries, where limited access to technology and teacher preparedness exacerbate the effectiveness of distance learning (Sato et al., 2023). International assessment data, such as PISA, show a widening gap in student performance, emphasizing the need for innovative pedagogical strategies to mitigate this impact (Liu et al., 2024).

In Indonesia, learning loss is a serious problem, especially at the junior high school level (Yusuf, 2023). Indonesian students lost around 11 - 12 months of learning during the pandemic, with vulnerable groups affected the most (Ssenyonga, 2021 ; Ugras et al., 2023). While the government launched initiatives such as Merdeka Belajar that support blended learning and teacher training, challenges remain (Widiastuti, 2025). Many schools still lack digital infrastructure, and teachers often struggle to integrate technology meaningfully into learning (Li, 2024). The return to face-to-face learning also reveals a lag in basic knowledge, particularly in STEM and literacy (Zhang et al., 2024). Without appropriate intervention, these deficits have the potential to undermine Indonesia's future human capital development and competitiveness (Ssenyonga, 2021).

The urgency of addressing learning loss is increasingly crucial as Indonesia commits to Sustainable Development Goal (SDG) 4, which is inclusive and quality education (Samala et al., 2024). However, current mitigation efforts tend to focus on remedial programmes or curriculum adjustments, without harnessing the potential of TPACK (Technological Pedagogical Content Knowledge) (Anderson & Putman, 2020). TPACK-a framework that combines technology, pedagogy and content expertise-offers a promising solution (Karanfiloğlu & Bulut, 2025). Global studies prove that teachers with TPACK competencies are able to design more adaptive and engaging learning, key to post-pandemic recovery (Lo et al., 2025). Unfortunately, empirical research on the role of TPACK in reducing learning loss in Indonesia is scarce. The majority of previous studies have only examined TPACK in pre-service teacher training or technology adoption, without examining its synergistic impact on student learning recovery in crisis contexts.

This research aims to fill this gap by investigating the implementation of TPACK to mitigate learning loss in Indonesian junior high schools. The study will assess teachers' TPACK competencies, identify barriers to its implementation, as well as measure the effectiveness of this framework in restoring students' academic attainment. The findings are expected to provide practical recommendations for policy makers and educators, aligned with national priorities such as Digital Education Transformation and the Guru Penggerak programme.

The novelty of this research lies in its focus on evaluating how effective the TPACK concept is in mitigating the occurrence of learning losses caused by challenges in the use of technology that are not entirely optimal. The study aims to investigate how the use of TPACK by teachers can help overcome the barriers to the utilization of technology in learning, as well as its impact on the quality of learning and the reduction of learning loss. By focusing on the link between teacher TPACK competence and increased learning effectiveness in reducing learning loss, the study can make an important contribution to understanding how technology can be used more effectively in addressing the educational challenges faced during the pandemic and in the future. By identifying strategies and best practices related to the use of TPACK in the face of technological challenges, this research can provide valuable insights for the development of more effective education and learning policies in the future.

2. METHODS

This study was conducted by involving junior high school teachers as the main population spread across Pelalawan Regency, Kampar Regency, and Pekanbaru City, Riau Province, Indonesia. The three areas were chosen on purpose to make sure there was a good mix of urban and rural settings, since education in these two types of places usually differs a lot in terms of available facilities and access to technology. The sampling technique used was stratified simple random sampling with special consideration to ensure the diversity of the research subjects.

From the total population, 735 teachers were selected as the initial sample. This number is considered adequate with a confidence level of 95% and a margin of error of 5%, in accordance with the recommendations of Hair et al. (2019) for research with a similar scale. After the data collection process, out of 735 questionnaires distributed, 725 were returned. After going through the verification process, 6 questionnaires were found to be ineligible due to unanswered items, so the total valid sample used in the analysis was 719 respondents. The questionnaire return rate reached 98.63%, which indicates an excellent level of participation in this study.

The research instrument used was an adaptation of the questionnaire developed by Mahdum et al. (2019) with some minor adjustments to suit the current research context. The questionnaire consists of 66 statements divided into four main sections. The first section contained respondents' demographic information, such as age, gender, and teaching experience. The second section focused on measuring ICT knowledge related to TPACK with 6 question items. The third section is the core of the questionnaire, which measures ICT utilization within the TPACK framework through 45 items. While the last section consisted of 15 items that specifically measured learning loss mitigation efforts. All statements used a 5-point Likert scale from strongly disagree to strongly agree.

The instrument validation process was conducted comprehensively through two main approaches. Content validity was tested by three experts in TPACK and ICT education using the Index of Content Validity (CVI). An item was declared valid if it achieved a CVI value of at least 0.78. All items in the questionnaire met this criterion after several revisions based on expert feedback. The reliability test was conducted on 30 teachers who were not included in the research sample. The calculation result of Cronbach's alpha showed a value of 0.894, far exceeding the minimum limit of 0.7 recommended by Geerinck et al. (2021), so the instrument was declared highly reliable for use.

Data collection was conducted through three main channels to ensure a high response rate. Distribution was done through official school emails, WhatsApp groups of junior high school teacher communities, and printed questionnaires for areas with limited internet connectivity. This multi-method approach proved effective, as a very high return rate was achieved.

Data analysis was conducted using IBM SPSS version 25.0, which was chosen for its ability to process large-scale data and provide a comprehensive range of statistical test tools. Descriptive statistical analysis was used to map the respondents' characteristics and the level of ICT-based TPACK utilization. While inferential analysis was conducted by first testing statistical assumptions such as the normality test using Kolmogorov-Smirnov/Shapiro-Wilk and the homogeneity test using Levene's Test.

3. FINDINGS AND DISCUSSION

3.1 Usage Rate of TPACK-Based ICT

Table 1 summarizes the general reaction of teachers to the implementation of TPACK-based ICT. When TPACK-based ICT was used, the maximum answer rate (39.50%) was obtained in the agree category, while the lowest response rate (4.70%) was discovered in the disagree category. In the meanwhile, the TPACK-based ICT variable of construction was discovered in a sequential manner using the following categories: strongly agree > agree > neutral > disagree > and strongly disagree. Additionally, the percentage values, from largest to smallest, in the instructors' reactions to learning loss mitigation utilizing PTACK-based ICT fell into the following categories: strongly agree, agree, neutral, disagree, and strongly disagree. Further presented in Table 1.

Table 1. The teacher's response to the use of TPACK-based IT conducted in schools

No	Variables	Responses (%)				
		SA	**A**	**N**	**D**	**SD**
1	Utilization of PTACK-based ICT	25.26	39.50	23.67	6.87	4.70
2	Construction of PTACK-based ICT	30.03	35.85	20.26	8.32	5.54
3	Mitigation of learning loss	30.75	36.39	19.17	8.47	5.22
	Average values	28.68	37.16	21.03	7.89	5.15

Noted; SA= strongly agree, A=agree, N=neutral, D=disagree, SD=strongly disagree.

Based on the data presented in Table 1, entitled *"Teachers' Responses to the Use of TPACK-Based ICT in Schools,"* it can be inferred that, overall, teachers exhibit a positive attitude toward the implementation of ICT-based TPACK (Technological Pedagogical Content Knowledge) in educational settings. The *"Agree"* category recorded the highest mean percentage at 37.16%, indicating that the majority of teachers support the integration of TPACK in the teaching and learning process. This finding reflects a strong level of acceptance toward the combination of technology, pedagogy, and content knowledge within the educational context.

A closer examination of the data reveals that the variable *"Mitigation of Learning Loss"* obtained the highest percentage in the *"Strongly Agree"* category at 30.75%. This suggests that teachers recognize the crucial role of TPACK-based ICT in minimizing learning loss, particularly in post-pandemic or distance learning contexts. The variable *"Construction of TPACK-Based ICT"* followed closely with a *"Strongly Agree"* percentage of 30.03%, indicating strong teacher support for the development and enhancement of TPACK-oriented ICT frameworks and approaches in instructional practice. Interestingly, the variable *"Utilization of TPACK-Based ICT"* received the lowest *"Strongly Agree"* percentage (25.26%) while also recording the lowest *"Strongly Disagree"* percentage (4.70%). This pattern suggests that although teachers generally endorse the use of TPACK-based ICT, certain challenges—such as limited infrastructure, insufficient technical proficiency, or constraints on time for technology adaptation—may hinder its full implementation in schools.

The overall average shows a fairly balanced distribution between strongly agree and agree attitudes, with the neutral category (21.03%) still quite significant, reflecting that some teachers do not yet have a strong position towards the implementation of TPACK. The disagree and strongly disagree categories are collectively below 13%, which reinforces the impression that resistance to TPACK is not a dominant issue. Thus, this table reflects that teachers have a high awareness of the importance of TPACK-based ICT integration in education but also hints at the need for additional support—both in the form of training, mentoring, and infrastructure to encourage the optimization of its use evenly and sustainably.

The level of use of TPACK-based ICT by teachers in junior high schools is summarized in Table 2. All variables such as TPACK-based ICT utilization, TPACK-based ICT construction, and learning loss mitigation obtained an average value of >3.5 with a high category. The values with high categories for all variables indicate that teachers and ICT are a very important role in the learning environment, and the need for ICT is considered vital in learning. More details are presented in Table 2.

Table 2. The level of use of TPACK-based ICT conducted by teachers in junior high schools

No.	Variables	Average	SD	Interpretation
1	Utilization of TPACK-based ICT	3.7402	1.055	High
2	Construction of TPACK-based ICT	3.7709	1.128	High
3	Mitigation of learning loss	3.7891	1.124	High

Notes: SD = standard deviation.

Table 2 illustrates that the level of TPACK-based ICT use by teachers in junior secondary schools is high for all variables measured. The three main aspects studied—utilization of TPACK-based ICT, construction of TPACK-based ICT, and mitigation of learning loss—all showed mean scores above 3.7 on a 5-point Likert scale, which is classified in the 'High' category. Specifically, the mitigation of

learning loss variable obtained the highest mean score of 3.7891, indicating that teachers most intensively used the TPACK approach in order to minimize learning loss. This reflects teachers' adaptive and strategic response to learning challenges, especially in the post-pandemic or emergency context of education. It also confirms the importance of utilizing technology integrated with pedagogy and content to maintain the continuity of student learning.

Furthermore, the variable Construction of TPACK-based ICT is in the second position with an average of 3.7709. This indicates that teachers are quite active in constructing or designing learning structures with the TPACK approach, which includes the integration of technology, teaching materials, and teaching methods. This is an important foundation in creating learning experiences that are contextualized and relevant to the needs of the times. Meanwhile, utilization of TPACK-based ICT recorded the lowest average among the three, at 3.7402. Although still in the high category, this lowest rating could indicate challenges at the actual implementation stage in the classroom—for example, related to access to devices, limited technical skills, or lack of institutional support.

From these three variables, it can be analytically concluded that teachers in junior secondary schools already have high awareness and commitment to the use of TPACK-based ICT in learning activities. However, there are opportunities for improvement, particularly in the utilization aspect, which points to the need for further training, infrastructure improvements, and stronger supporting policies to ensure that TPACK implementation is more optimal and sustainable in supporting educational transformation.

3.2 The Structure of the Relationship Model for the Use of TPACK-ICT

Table 3 summarizes the connection between TPACK-based ICT use and learning loss prevention. Learning loss mitigation is significantly impacted by the factors of TPACK-ICT construction and TPACK-ICT consumption, which have a positive connection ($p<0.05$). The results showed that the beta coefficient values were 0.837 and 0.861, respectively. This indicates that this investigation validated hypotheses H_1 and H_2. The utilization of TPACK-based IT in the learning process was also shown to be positively and significantly impacted by TPACK-ICT construction ($p<0.05$). It was discovered that the beta coefficient was 0.839. This result also demonstrated that this investigation supported hypothesis H_3.

Table 3. Structural model estimation and hypothesis testing on the use of TPACK-based ICT conveyed by teachers

Hypothesis	Path	Coefficient ß	t-test	Sig. (p values)	Results
H_1	Construction of TPACK-based ICT– Mitigation of Learning loss	0.837	4.852	0.000	supported
H_2	Utilization of TPACK –based ICT– mitigation of learning loss	0.861	8.501	0.000	Supported
H_3	Construction of TPACK-based ICT– Utilization of TPACK-based ICT	0.839	9.254	0.000	supported

Based on Table 3, entitled 'Structural model estimation and hypothesis testing on the use of TPACK-based ICT conveyed by teachers,' there is strong empirical evidence of the relationship between the construction and utilization of TPACK-based ICT and the mitigation of learning loss in schools. All hypotheses tested—H_1, H_2, and H_3—were statistically supported with a significance value of 0.000 ($p < 0.05$), indicating a highly significant relationship between the variables under study.

The first hypothesis (H_1) shows that teachers' construction of TPACK-based ICT has a significant positive relationship with learning loss mitigation, with a β coefficient of 0.837. This means that the stronger teachers construct or design TPACK-based learning, the more effective their efforts are in preventing learning loss in students. This suggests that the quality of ICT-based learning design is not only important theoretically but also has a real impact on educational practice.

The second hypothesis (H_2) confirmed that teachers' utilization of TPACK-based ICT also has a significant impact on mitigating learning loss, with a β coefficient of 0.861, the highest among the three relationships tested. This implies that the appropriate implementation of technology in the learning process plays a huge role in maintaining the continuity of student learning. In other words, teachers' ability to use ICT effectively and contextually is an important key in dealing with learning disruption.

Furthermore, the third hypothesis (H3) confirmed that there is a positive and significant relationship between TPACK-based ICT construction and its utilization by teachers, with a β coefficient of 0.839. This means that teachers who design ICT with a mature TPACK approach tend to be more able to utilize it effectively in practice. This confirms that a good design process (pedagogical and technological) will lead to improved quality of implementation in the classroom. Analytically, the results of this table reinforce the understanding that the successful use of ICT in education does not solely depend on the availability of technology but on the competence of teachers in constructing and integrating ICT pedagogically and contextually through the TPACK framework. This provides a strategic basis for future policy making and teacher training programs, especially in the context of post-pandemic recovery and accelerating the digital transformation of education.

3.3 Contribution of Using TPACK-ICT in Learning

The strength of the relationship between the use of TPACK-based ICT and the mitigation of learning loss is shown in Table 4. A positive relationship of 0.837 with the category of strong correlation was found between the construction of ICT-TPACK and learning loss mitigation 0.837 with the category of "strong correlation" was found between the construction of ICT-TPACK and learning loss mitigation. Meanwhile, the variable of ICT-TPACK utilization also obtained a positive relationship with the prevention of learning loss in a strong correlation category. The relationship between the variable of ICT-TPACK construction and the variable of TPACK-ICT utilization was also found to have a positive relationship with a strong correlation.

Table 4. The strength of the relationship between variables was analyzed with the value of the correlation coefficient

Variables	Construction of TPACK-based ICT	Utilization of TPACK-based ICT	Mitigation of learning loss
Construction of TPACK-based ICT	-		
Utilization of TPACK-based ICT	0.839	-	
Mitigation of learning loss	0.837	0.861	-

Table 4 shows that there is a very strong relationship between the three variables studied, namely TPACK-ICT construction, TPACK-ICT utilization, and learning loss mitigation. The highest correlation coefficient emerges between TPACK-ICT utilization and learning loss mitigation (r = 0.861), indicating that the higher the level of TPACK utilization by teachers, the greater the contribution to reducing learning loss. A strong relationship was also observed between TPACK-ICT constructs and their utilization (r = 0.839), as well as between TPACK-ICT constructs and learning loss mitigation (r = 0.837). This data reflects that a well-thought-out TPACK-based learning design not only encourages teachers to implement it but also has a real impact on minimizing the impact of learning loss, especially in the post-pandemic era.

The results of this analysis show that the improvement of construction and utilization of TPACK-ICT can directly strengthen the effectiveness of mitigating learning loss in schools. Therefore, strategic efforts in teacher training should focus on developing competencies in designing and implementing TPACK-based learning. The synergy between thorough planning and the use of TPACK in learning practices has proven crucial for overcoming learning gaps, especially in the context of post-pandemic education.

3.4 Mediation Analysis of the TPACK-ICT Use in Learning

A path analysis to examine the relationship between the construction of TPACK-based ICT and its use as a mediator in mitigating learning loss is summarized in Table 5. As shown in Table 5, the variable of TPACK-based ICT construction and the use of TPACK-based ICT as a mediator showed a very significant impact on the prevention of learning loss ($p<0.05$) in high school students during learning in the COVID-19 era. Where the value of the analysis coefficient was 0.887. This indicated that the variables of TPACK-based ICT construction and TPACK-based ICT utilization were effective in contributing as mediators in the mitigation of learning loss in junior high schools in the COVID-19 era.

Table 5. Path analysis achieved from the simultaneous relationship between the variable of TPACK-ICT construction, TPACK-ICT utilization, and learning loss mitigation

Hypothesis	Mediated pathway	Path coefficient ß	t-test	Sig. (p-value)
H_4	Construction of TPACK-based ICT - utilization of TPACK-based ICT – Mitigation of learning loss	0.887	0.918	0.000

Meanwhile, the equation of multiple linear regression for the construction of TPACK-based ICT and the utilization of TPACK-based ICT toward the mitigation of learning loss was obtained: $y = 0.400 X_1 + 0.597 X_2 + 0.048$. This equation shows that: 1) if the construction of TPACK-based ICT and the utilization of TPACK-based ICT in the object of study are equal to zero (0), then the prevention of learning loss in learning in the COVID-19 era is obtained at 0.048. 2) The value of the X_1 coefficient was found to be 0.400 with a positive value. This value showed that if the construction of TPACK-based ICT was increased by one unit, there would be an increase in learning loss prevention of 0.400. 3) The coefficient of X_2 was found to be 0.597 with a positive value. This value demonstrated that if the use of TPACK-based ICT was increased by one unit, then an increase in learning loss prevention would be found at 0.597.

The value contributed to the use of TPACK-based ICT for the mitigation of learning loss conveyed by teachers in junior high schools in the COVID-19 era is illustrated in Figure 1. The mitigation of learning loss was influenced by the variable of TPACK-based ICT construction with a value of 83.7%, and other constructs that were not examined in this study had an impact of 16.3%. The mitigation of learning loss was also influenced by the use of TPACK-based ICT, with a value of 86.1%, and other variables not reported in this study accounted for a value of 13.9%. Meanwhile, the use of TPACK-based ICT was influenced by the variable of TPACK-based IT construction, with a value of 83.9%, and other variables not examined in this study accounted for 16.1%. Simultaneously, the variables of constructing TPACK-based ICT and the utilization of TPACK-based ICT for mitigating learning loss contributed 88.7%, and other variables not reported in this study contributed 11.3%. Image 1 illustrates this explanation in its entirety.

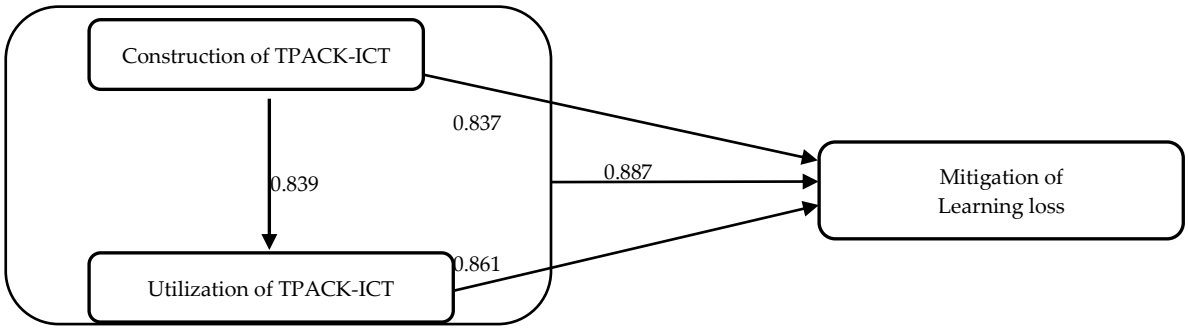

Figure 1. The estimation of the contribution of TPACK-based ICT toward the mitigation of learning loss conducted during the Covid-19 pandemic

Figure 1 illustrates the estimated contribution of TPACK-ICT in mitigating learning loss during the COVID-19 pandemic. The diagram shows that the construction of TPACK-ICT (β = 0.837) and its utilization (β = 0.861) directly contribute to mitigating learning loss, with a total contribution of 88.7%. Moreover, there is a strong relationship between the construction and utilization of TPACK-ICT (β = 0.839), indicating that a good understanding and design of TPACK will encourage more effective use of ICT in learning. The implication of these findings is the importance of enhancing teachers' capacity to build and implement TPACK-ICT in an integrated manner as a primary strategy to address the impact of ineffective online learning. Therefore, teacher training programs need to focus on strengthening technology-based pedagogical competencies holistically.

3.5 Teacher's Perspectives and Expectations

Based on the results of quantitative analysis and visualization of the TPACK-ICT contribution model to mitigate learning loss, teachers' perspectives and expectations show a complex dynamic that reflects both challenges and hopes regarding the use of technology in learning. In general, teachers acknowledge that the construction and utilization of TPACK-ICT played a significant role in reducing learning loss during the pandemic, but on the other hand, they face structural obstacles such as limited digital infrastructure, low technological literacy, and minimal ICT-based pedagogical training. Data shows that a strong TPACK construction will encourage more optimal utilization, which in turn increases the effectiveness of learning. However, many teachers still do not fully understand the integration of technology, pedagogy, and content as a whole, so the implementation of TPACK tends to be purely technical, not yet touching on the reflective-critical aspects in learning design. Teachers' expectations for the future include stronger systemic support, contextual and continuous training, and equitable access to educational technology. Therefore, educational policies must move beyond a technocratic approach towards a transformative model that empowers teachers as the main actors in TPACK-based digital education innovation.

The results of this study clearly reinforce the relevance and urgency of utilizing TPACK in mitigating learning loss at the junior high school level, particularly in Riau Province. The significant contribution of the TPACK-ICT construct and its utilization, which can explain up to 88.7% of the variation in efforts to mitigate learning loss, indicates that the integration of technology in pedagogical practices is not just an option but a strategic necessity. In the context of Riau, which geographically and infrastructurally still faces the challenge of digital inequality, these findings serve as an important foundation to promote more contextual and data-driven educational policies. The effective implementation of TPACK not only improves the quality of online and offline learning but also serves as a concrete solution to reduce the learning outcome gap between regions. Thus, this study provides empirical evidence that the utilization of TPACK is a viable and impactful approach to addressing the challenge of learning loss in junior high schools in areas significantly affected by the pandemic.

The analysis of teachers' perspectives and expectations in this study employed a descriptive narrative approach, structured around qualitative data collected through open-ended questions and additional comments on the Likert scale questionnaire. The narratives in these findings have been thematically categorized into three main issues: infrastructure barriers, pedagogical challenges, and institutional support. Infrastructure barriers include limited ICT devices and unstable internet networks, while pedagogical challenges encompass teachers' lack of understanding of TPACK construction and utilization. On the other hand, uneven institutional support also hinders the effectiveness of TPACK integration.

Discussion

In the context of learning during the COVID-19 pandemic, the issue of learning loss is critical, especially at the junior high school level in Indonesia (Nirmala et al., 2024; Rohmah et al., 2024). Research shows that the utilization of TPACK (Technological Pedagogical Content Knowledge) has a significant contribution in reducing learning loss (Yani et al., 2025 ; Backfisch et al., 2024 ; Ong &

Annamalai, 2024 ; Bouhout et al., 2024). Specifically, this study revealed that there is a positive and significant relationship between teachers' knowledge in building ICT-based TPACK and learning loss mitigation. This is measured by showing the use of ICT-based TPACK, which explains about 88.7% of the variation in learning loss mitigation efforts.

Nonetheless, the research also found that teachers face various challenges in implementing TPACK. Some of the obstacles identified include limited infrastructure, such as inadequate ICT devices and unstable internet networks and this is certainly in line with previous research (Mugizi & Nagasha, 2025 ; Barikzai et al., 2024 ; Mustafa et al., 2024 ; Yu et al., 2024). In addition, teachers' lack of understanding in the construction of TPACK and its utilisation is a major obstacle to effective implementation (Al-Adwan et al., 2025 ; Max et al., 2024 ; Karataş & Ataç, 2024). With these results in mind, education policy strategies should go beyond a technocratic approach. There is an urgent need to implement transformational models that empower teachers as key actors in digital-based educational innovation.

Research on the utilisation of TPACK (Technological Pedagogical Content Knowledge) to mitigate learning loss in junior secondary schools has significant implications for future educational developments. One of the most important aspects of these findings is the need for teacher competence development and this corroborates previous research (Arstorp et al., 2024 ; Norhagen et al., 2024 ; Yayuk & Haqqi, 2024). In this context, training and professional development programmes should focus more on the integration of technology in teaching. This means that teachers need to understand not only the technical aspects but also how to link technology with pedagogical methods and relevant content. With contextualised and continuous training, teachers will be better equipped to implement adaptive and engaging learning strategies for students.

In addition, this study shows the need for the integration of TPACK into the teacher education curriculum. Educators who are trained to not only understand the theory but also gain hands-on practice in using technology in teaching will be better able to face the challenges of the digital age (Msimango et al., 2024 ; Kiryakova & Kozhuharova, 2024). Therefore, education policy needs to adopt an approach that ensures that all schools, including those in remote areas, have access to adequate digital infrastructure. Investment in the digitisation of education should be a government priority to ensure that learning is not hampered by technological limitations.

Education policies should also be geared towards creating an inclusive and sustainable education system (Zorde & Lapidot, 2025 ; Hajisoteriou & Sorkos, 2023). The emerging disparity between urban and rural areas in access to education during the pandemic calls for collaboration between the government, the private sector, and educational institutions (Babbar & Gupta, 2022). This can create a more equitable education ecosystem where all students, regardless of geographical and socio-economic backgrounds, have the opportunity to learn well (Liu, 2025). This requires a shift towards a transformational policy model, where teachers are empowered to play an active role in curriculum development and technology integration (Abedi, 2024 ; Schmitz et al., 2023). By giving teachers a voice in decision-making relating to the use of technology, they will feel more involved and responsible for student learning outcomes (Geurts et al., 2024). With these measures, the education system is not only able to overcome the impact of learning loss due to the pandemic but also build stronger educational resilience to face future challenges (Borazon & Chuang, 2023 ; Sato et al., 2023). Thus, the implications of this research are not only relevant for the present but also have the potential to shape a better, balanced, and adaptive future for education.

4. CONCLUSION

This research makes a significant contribution to the literature on the use of TPACK as a learning loss mitigation strategy during the pandemic, particularly in the Indonesian context. Through an empirical approach, this study not only confirms the strong relationship between the construction and utilization of TPACK-ICT and the reduction of learning loss but also highlights the structural factors that are key barriers, such as access to digital infrastructure and teachers' pedagogical competence. By

positioning TPACK as a key cornerstone, this study enhances the understanding of how holistic technology integration can improve the effectiveness of learning processes, particularly in crisis situations. Moreover, this study places the strategic role of teachers as the main actors in the digital transformation of education, emphasizing the importance of continuous and contextual professional competence development. In terms of practical policy, the study results indicate the need for governments and educational institutions to strengthen digital infrastructure evenly across regions while creating training programs that are not only technical but also critical and reflective of technology-based learning design. In addition, TPACK-based approaches should be integrated into the teacher education curriculum to address the complex challenges in the field and prepare teachers as agents of pedagogical innovation who are adaptive to technological dynamics. Thus, this study confirms that building an educational ecosystem that supports the mastery of TPACK is a strategic step to reduce the learning gap while strengthening the competitiveness of Indonesia's human resources in the future.

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