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Enhancing TPACK through Collaborative Practices: Evaluating the Impact of Vocational Teacher Collaboration on Technological Integration

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Abstract

This study explores the role of collaborative practices in enhancing Technological Pedagogical Content Knowledge (TPACK) among vocational teachers in Yogyakarta, Indonesia, and identifies barriers to effective technology integration. The research involved 30 vocational teachers with leadership roles and teaching experience of more than five years, representing a critical group in advancing technology-supported vocational education. A quantitative approach was used, combining survey data on the frequency of barriers with descriptive analysis of collaborative practices. The results indicate that while many teachers demonstrate meaningful engagement in collaborative practices, participation is uneven and often constrained by limited time, inadequate access to technological resources, and misalignment between curriculum and technology. More than half of the teachers reported frequently experiencing barriers to technology integration, with the most significant challenges being heavy workloads, insufficient training, and infrastructure limitations. Nonetheless, the findings also reveal promising practices, as some teachers actively eng age in peer collaboration and professional development, highlighting the potential of structured support systems. The study concludes that although collaboration among vocational teachers is progressing, systemic gaps remain that hinder equitable and consistent TPACK implementation. To address these challenges, stronger institutional frameworks are required, including professional learning communities, continuous professional development, curriculum adaptation, and enhanced collaboration with higher education institutions. Such measures would provide sustained support, improve teachers' technological competence, and ensure that vocational education is better positioned to meet the demands of the digital era.

Keywords: *Education Quality, Education Partnership, Innovation, Technology Integration, Vocational Teacher*.

1. Introduction

Technological Pedagogical Content Knowledge (TPACK) is a knowledge framework that integrates technology, pedagogy, and content in the learning process [1][2][3]. In vocational education, TPACK plays a crucial role because it helps teachers integrate technology into both practical and theoretical learning, enabling students not only to understand the material but also to develop the skills to apply technology according to industry needs [2][4]. Through TPACK, teachers can design technology-based teaching strategies that are relevant, interactive, and oriented toward work competencies, while also ensuring that learning remains meaningful for students [5][6].

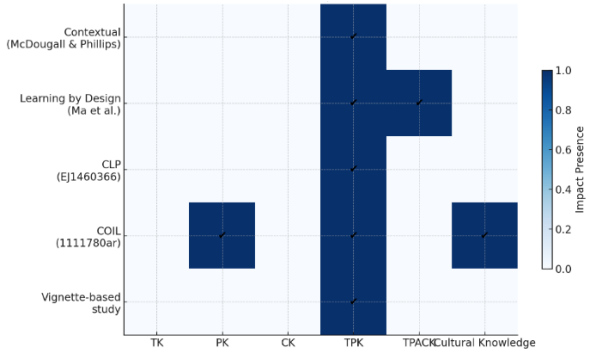

Fig 1. Collaboration Practice Impact on TPACK Elements

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The analyzed articles collectively highlight how collaborative practices can strengthen teachers' competencies, particularly within the TPACK framework. The first article, [7], emphasizes online team-teaching and joint reflection, which help preservice teachers integrate technology with pedagogical strategies, thereby reinforcing TPK. The second article, [8], employs a learning-by-design approach in the context of corpus-based pedagogy, with intra- and inter-group collaboration fostering the development of CK, TK, PK, and TPK, leading to a more specific integration of TPACK. The third article,[9], focuses on collaborative lesson planning (CLP), where discussions, feedback, and role-sharing encourage preservice teachers to connect TK with teaching strategies (PK), resulting in more mature TPK.
Meanwhile, the fourth article, [10], expands the TPACK framework through Collaborative Online International Learning (COIL), which not only strengthens PK and TPK but also introduces a new dimension, cultural knowledge, giving rise to the notion of TPACK-CK. The fifth article, [11][12], highlights vignette-based collaboration using digital collaborative tools (such as ZumPad) and a group puzzle model, underscoring the role of collaboration in enhancing TPK through the close interplay between technology selection and pedagogical strategies. Overall, these five studies demonstrate that collaborative practices—in the form of planning, co-teaching, inter-group design, or cross-cultural exchange—are effective strategies to strengthen the integration of technology, pedagogy, and content in educational practice.
Various collaborative strategies have proven effective in the development of TPACK, both for pre-service teachers and experienced educators. Peer collaboration, mentoring, participation in workshops, and reflective practice serve as key avenues for enhancing technology-based pedagogical skills [13][14]. For example, a community service initiative in East Aceh demonstrated that collaborative workshops significantly strengthened teachers' TPACK competencies [15][16]. However, vocational teacher collaboration practices in Indonesia have not yet fully integrated technological skills. Many teachers still tend to focus on pedagogical and content aspects, while mastery of technology remains inconsistently incorporated into collaborative activities. This has often resulted in suboptimal efforts to strengthen TPACK. In addition, challenges such as limited resources, low teacher confidence in using technology, and uneven digital skills further hinder the integration of TPACK [13]. In this context, sustained collaborative support—such as personalized mentoring, technological capacity-building, and tiered training—emerges as a strategic solution to overcome these barriers [16]. Moreover, teachers' professional identity and self-efficacy also play an important role in the successful implementation of TPACK in vocational education. The success of technology integration depends not only on cooperation and external support but also on teachers' belief in their own ability to utilize technology in teaching [17] [18] [19].
As of 2025, recent literature indicates that TPACK research has entered a mature phase—marked by numerous systematic reviews and framework modifications reassessing the role of Technological Knowledge (TK), the integration of AI, and teacher training models. Accordingly, the research focus has shifted from merely measuring TPACK levels to developing and sustainably integrating them through structured interventions. Systematic reviews and review-of-reviews consistently highlight theoretical advances in TPACK, yet the practical implementation (mastery of TK and integration of TK–PK–CK) remains uneven across contexts. Recent studies also emphasize the entry of Artificial Intelligence (AI) as a new factor shaping teachers' TPACK competence profiles—presenting both opportunities and the need for new training[20]. Meanwhile, studies in Indonesia (e.g., evaluations of the teacher professional education program and research on vocational competencies) reveal policy efforts and professional development initiatives that have begun to adopt TPACK principles, though they have yet to sufficiently bridge implementation gaps in vocational schools. Furthermore, strong evidence shows that collaborative practices and focused professional learning (communities of practice, knowledge-sharing, inter-teacher collaboration programs) effectively enhance technological proficiency and TPACK application[21]. However, most studies remain sectoral (specific subject areas) or short-term (limited intervention duration), with relatively few experimental or longitudinal investigations examining how guided vocational teacher collaboration (e.g., facilitation models, school leadership support, industry access) directly improves industry-relevant technology integration over the medium to long term[22]. Therefore, the research gap addressed in this study lies in the need for rigorous empirical evidence—particularly within the Indonesian vocational education context—on the extent to which teacher collaborative practices can enhance TK and TPACK integration relevant to industry tools/AI/technologies, as well as the institutional conditions (infrastructure, leadership, higher education support) that moderate such effects.
The novelty of the study "Enhancing TPACK through Collaborative Practices: Evaluating the Impact of Vocational Teacher Collaboration on Technological Integration" lies in its collaborative approach as a core strategy to enhance vocational teachers' TPACK mastery, which has traditionally been addressed through individual training or short-term workshops. This research explores how interactions among vocational teachers—in the form of sharing experiences, co-designing lessons, and collectively solving problems of technology integration—can accelerate the mastery of Technological Knowledge and strengthen the interconnectedness of content, pedagogy, and technology, including through collaboration with Higher Education institutions. Another novelty is the focus on the Indonesian vocational education context, which faces unique challenges such as infrastructure gaps, limited resources, and the demands of linkage with Industry 4.0 toward Society 5.0. Thus, this study offers an original contribution in the form of a collaborative model involving vocational teachers, universities, industry, and peers, which has the potential to serve as a sustainable alternative for improving educational technology integration while also providing an empirical basis for more contextual and applicable teacher professional development policies.

2. Methods

This study employs a quantitative method to measure the extent to which technology integration through collaborative practices can develop TPACK among vocational teachers [23] [24].

2.1 Research Context

This study was conducted in the context of vocational education in Indonesia, focusing on the integration of technology into teaching practices through collaborative approaches. The research aims to evaluate how collaboration among vocational teachers can enhance their Technological Pedagogical Content Knowledge (TPACK) and support effective technology integration in teaching and learning processes. The setting was vocational high schools (Sekolah Menengah Kejuruan or SMK) in the Special Region of Yogyakarta (DIY), a region recognized for its strong commitment to vocational education development.

2.2 Participant

The participants of this study consisted of 30 vocational teachers who hold strategic academic or managerial roles, namely koordinator laboratorium (laboratory coordinators), koordinator bidang (field coordinators), and kepala departemen (heads of department). All participants had more than five years of teaching experience and were within the age range of 25 to 45 years, ensuring that they possessed both professional maturity and relevant teaching exposure to reflect on technology integration within vocational education.

2.3 Data Source and Analysis

The primary data were collected through survey questionnaires to capture teachers' experiences, perceptions, and practices in integrating technology into vocational education. The instruments focused on assessing the teachers' TPACK dimensions—technological, pedagogical, and content knowledge—alongside their collaborative practices and challenges in technology integration.

The study employed a quantitative approach to data analysis. Quantitative data from the survey were analyzed using descriptive and inferential statistics with the aid of SPSS software to identify trends and relationships between collaboration practices and TPACK development.

3. Results and Discussion

The results of this study provide a comprehensive understanding of how collaboration practices shape the development of vocational teachers' TPACK, the challenges they encounter in integrating technology, and the ways in which collaborative efforts can facilitate effective technological integration in teaching. The discussion begins with an exploration of the nature and forms of collaboration practices among vocational teachers, followed by an analysis of the obstacles that arise when adopting and embedding technology in instructional processes. Finally, the discussion highlights how collaboration not only addresses these challenges but also serves as a catalyst for strengthening technology integration, ultimately enhancing pedagogical innovation and professional growth.

3.1. Collaboration Practices

Of these, however, the important ones to present challenges to the teacher are those of time, resources, and matching curricula to available technology.

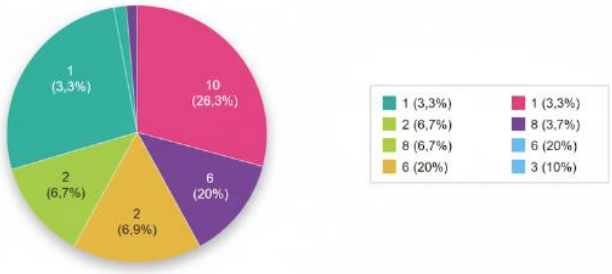

Fig 2. Collaboration Practices

The findings of this study, based on responses from 30 vocational teachers in Yogyakarta, reveal varying levels of engagement in collaborative practices to enhance TPACK. The distribution of responses shows that the largest proportion, 10 teachers (26.3%), reported high involvement in collaborative practices, indicating a relatively strong orientation toward joint efforts in integrating technology into teaching. Meanwhile, 6 teachers (20%) also showed considerable engagement, demonstrating the presence of consistent collaboration across institutions. Another 6.9% (2 teachers) and 6.7% (2 teachers) reflected moderate involvement, while smaller proportions were found among those with very limited collaborative engagement, namely 1 teacher (3.3%) and 1 teacher (3.7%). A notable 10% (3 teachers) indicated occasional or situational involvement.

The challenges faced by vocational teachers in implementing collaborative practices for TPACK integration are multifaceted. One of the most pressing issues is the limited availability of time. With busy schedules filled with teaching responsibilities, lesson planning, and administrative tasks, teachers often struggle to find adequate opportunities for meaningful collaboration with their colleagues. Another significant challenge is access to resources. In many cases, teachers do not have sufficient access to technological devices or the necessary infrastructure, which hinders their ability to effectively apply TPACK in classroom practices. Additionally, curriculum alignment poses its own difficulties. Many curricula are not designed to support, let alone integrate, technology, thereby requiring teachers to demonstrate a high level of adaptability and flexibility in order to embed technology within their existing instructional frameworks.

Overall, the results illustrate that while a significant number of vocational teachers are already actively involved in collaborative practices for TPACK development, the distribution also highlights a gap in consistent and structured collaboration. The presence of smaller groups of teachers with low or irregular participation suggests that collaborative initiatives have not yet been fully institutionalized across all vocational schools in the region.

When compared with collaborative practices in other countries, the findings highlight both similarities and differences. In advanced educational systems such as Finland and Singapore, teacher collaboration for technology integration is often embedded within professional learning communities (PLCs), supported by institutional frameworks that encourage peer mentoring, joint lesson planning, and reflective practice. These models ensure that collaboration is systematic, continuous, and aligned with national digital education strategies. Similarly, in the United States, collaborative approaches are frequently formalized through structured professional development programs and partnerships between universities and schools, providing teachers with ongoing access to technological training and shared resources.

Studies from the Philippines and Vietnam suggest that vocational and senior-high teachers often rate their overall TPACK competence moderately high, yet technological knowledge (TK) and consistent technology use remain uneven, especially under emergency remote teaching conditions[25][26].

The evaluations of TPACK development in teacher education programs point to promising gains from structured training, but they also highlight that embedding technology authentically into pedagogical and content courses (rather than treating technology as an add-on) is crucial for sustained teacher uptake. This resonates with our finding that some teachers engage actively in collaboration while others lag — likely because systemic embedding and consistent school-level supports are variable [27].

The experience with Professional Learning Communities (PLCs) shows how institutionalized collaborative structures (regular meeting time, shared goals, facilitation, and reflection protocols) can make teacher collaboration for technology integration systematic and scalable across schools [28]. Where PLCs or similar formalized structures exist, teachers report more sustained and aligned integration of pedagogy, content, and technology — a contrast with the more ad hoc or uneven collaboration observed in our DIY sample.

Lesson-study and other structured collaborative approaches used in some vocational/technical contexts have been reported to improve vocational teachers' TPACK through cyclical planning, observation, and reflective refinement of lessons. These models emphasize joint lesson design and hands-on practice with technology, which aligns with meta-analytic evidence showing that teacher-education interventions and sustained, practice-oriented PD produce large positive effects on TPACK (effect size ~0.84). Such evidence suggests that brief or one-off workshops are less likely to close the gap than ongoing, practice-embedded collaboration.

By contrast, the Indonesian context, as reflected in this study, demonstrates that collaboration among vocational teachers is present but still uneven and largely dependent on individual or school-level initiatives rather than a system-wide framework. The relatively high proportion of teachers with active engagement indicates a promising trend, but the existence of teachers with minimal participation suggests structural challenges, including limited resources, unequal access to training, and varying levels of digital literacy.

Putting it all together, the research indicates that vocational teacher collaboration in DIY is progressing: there is meaningful engagement in TPACK development by many teachers. But there remain gaps for consistent and equitable integration of the technological component across all teachers. The international literature suggests that to close those gaps, systemic support and institutionalization are necessary—through sustained professional development, inclusion of technology in content pedagogy rather than as an add-on, formal PLCs or departments with mandates for collaboration and shared planning, and interventions that emphasize hands-on practice with technology. A distinctive finding from this study, however, lies in highlighting the potential of collaboration between vocational schools and higher education institutions. Partnerships with universities can not only provide access to cutting-edge technological resources and expertise but also foster joint research, mentorship, and curriculum innovation that directly strengthen TPACK implementation at the school level. This cross-institutional collaboration represents an innovative pathway for ensuring that vocational teachers are not working in isolation but are continuously supported by academic networks and knowledge hubs that accelerate their professional growth in integrating technology with pedagogy and content.

3.2. Challenges on Technology Integration

The data analysis on the frequency of barriers experienced in technology integration shows a significant distribution across three levels. More than half of the respondents (56.7%) reported that they often experience barriers in integrating technology into their teaching practices. Meanwhile, 30% of teachers reported rarely experiencing barriers, suggesting that some teachers have managed to cope with or minimize obstacles. However, 13.3% of teachers reported very often experiencing barriers, indicating persistent challenges that may severely hinder effective technology adoption in vocational education.

The most frequently reported barriers included time constraints, limited access to devices and infrastructure, lack of adequate training and support, and insufficient curriculum alignment with technology use. These challenges collectively illustrate that, while teachers recognize the importance of integrating technology into their pedagogy, practical constraints often limit its optimal implementation.

The frequency distribution is summarized in Table 1 and visually represented in Figure 1.

Table 1. Frequency of Barriers Experienced in Technology Integration

Category	Frequency (%)	Interpretation
Rarely experience barriers	30.0%	Teachers occasionally face minor obstacles.
Often experience barriers	56.7%	Majority of teachers encounter regular barriers.
Very often experience barriers	13.3%	A smaller group of teachers face persistent and severe barriers.

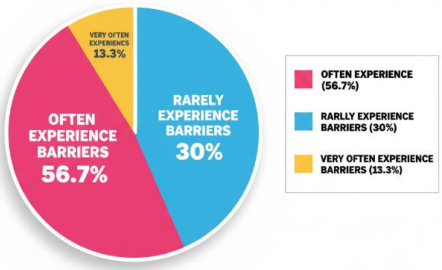

Fig 3. Distribution of Barriers in Technology Integration

The predominance of teachers who reported frequent barriers (56.7%) underscores that integrating technology in educational practice is still far from seamless. This finding is consistent with earlier research highlighting infrastructural challenges, such as limited access to digital devices and inadequate internet connectivity, as persistent obstacles in schools. These infrastructural issues restrict teachers' ability to adopt and sustain technology-enhanced pedagogical practices [29][30].

The second major barrier relates to teachers' lack of training and digital competence, which limits their confidence and preparedness in applying technology effectively in the classroom. This aligns with the TPACK framework[2], which emphasizes the need for teachers to

develop not only technological knowledge but also the ability to integrate it with pedagogy and content knowledge. Without sufficient professional development and support, technology adoption remains surface-level rather than transformative.

Time constraints also emerged as a key challenge, given teachers' heavy workload that often prevents them from experimenting with new digital tools. This resonates with previous findings, showing that organizational factors such as time and workload management significantly affect teachers' capacity to innovate with technology. Additionally, the lack of curriculum alignment suggests that integrating technology often depends on individual teacher initiatives rather than systemic guidelines, which may create inconsistency in classroom practices.

Interestingly, while 30% of teachers reported rarely experiencing barriers, this indicates that a portion of educators may already have better infrastructure, training, or support systems that enable smoother technology use. However, the fact that 13.3% very often experience barriers highlights inequity: some schools or teachers are disproportionately affected by systemic challenges.

The challenges faced in this study mirror global findings. For example, research in India and several African countries highlights similar barriers related to infrastructure and resource shortages, where digital divides limit the consistent adoption of technology[31][32][33]. In contrast, studies in more developed countries, emphasize that the central issue lies not in infrastructure but in the need for continuous professional development and sustained collaboration models to strengthen teachers' confidence in using digital tools [34]. Indonesian vocational teachers appear to be situated between these two conditions: while infrastructure issues persist, there is also a lack of systemic and institutionalized professional learning communities (PLCs) to sustain collaborative engagement.

These findings highlight the importance of multilevel interventions. Schools need to provide adequate infrastructure and allocate specific time for collaborative professional activities so teachers can share practices and co-develop digital teaching strategies. Policymakers should emphasize the inclusion of technology in the curriculum framework to encourage consistent integration across subjects. Furthermore, collaboration with universities can serve as a strategic approach to mentoring teachers, conducting joint training, and piloting innovative pedagogical models. Such collaborations could help bridge the gap between policy directives and classroom realities, ensuring that teachers are not left alone in integrating TPACK.

This study contributes novelty by underlining the strategic role of collaboration between vocational teachers and higher education institutions. While prior studies have largely emphasized teacher-to-teacher collaboration, this research demonstrates that sustained partnerships with universities are essential for overcoming technological barriers. Universities can provide not only technical training but also research-based interventions that help align curriculum, pedagogy, and technology in vocational education. This finding adds to the literature by identifying a systemic collaboration model that strengthens TPACK development in resource-limited contexts.

In summary, the study shows that vocational teachers in Yogyakarta continue to face frequent barriers in integrating technology, predominantly due to limited infrastructure, inadequate training, and misaligned curricula. Compared with international contexts, these challenges align with conditions in developing countries, but differ from developed nations where professional development is the primary focus. The implication is clear: policy and leadership must institutionalize collaboration, provide continuous professional development, and ensure curriculum flexibility. Most importantly, collaboration with universities emerges as a key innovative solution, bridging gaps in practice and offering sustained support for TPACK enhancement. This comprehensive strategy ensures that vocational education is better prepared to meet the challenges of the digital era.

3.3. Collaboration Practices on Technology Integration

This study set out to evaluate the impact of vocational teacher collaboration on the integration of technology within the TPACK framework. The results demonstrated a consistent and positive association between structured collaborative practices and enhanced teacher capacity to integrate technology meaningfully into their pedagogical designs. The quantitative findings converge to highlight that collaboration functions as a catalyst in transforming isolated technological skills into pedagogical knowledge that is relevant, contextualized, and sustainable. Quantitative analysis indicated significant improvements in teachers' overall TPACK scores following the collaborative intervention:

Table 2. Descriptive Statistics of Teachers' TPACK Scores (N = 30)

Condition	N	M	SD
Pre-test	30	3.12	0.36
Post-test	30	3.59	0.48

Table 3. Paired Samples t-test Results for Teachers' TPACK Scores

Test	t	df	p	Cohen's d
Pre vs. Post	9.09	29	< .001	1.66

The largest gains were observed in Technological Knowledge (TK) and its intersections with pedagogy and content (TPK, TCK), suggesting that collaboration accelerates the adoption of technical skills and their pedagogical application. Teachers consistently described collaboration as a mechanism for "sharing practical shortcuts," "co-designing lessons," and "receiving peer feedback," which facilitated both confidence and creativity in using technology.

These findings reinforce the social constructivist view that knowledge is co-constructed through interaction. More specifically, collaboration operates through two complementary mechanisms: (1) exposure-performance—teachers acquire new technological skills through observation, modeling, and practice; and (2) reflection-design—teachers collectively transform these skills into pedagogical strategies through dialogue, problem-solving, and iterative redesign. Thus, collaboration bridges the gap between knowing technology and using technology to teach.

Importantly, the effects of collaboration were not evenly distributed across TPACK domains. While TK and TCK improved rapidly due to their practical and observable nature, PK and PCK developed more slowly, requiring deeper pedagogical reflection and classroom experimentation. Fully integrated TPACK competence, therefore, appears to be an outcome of iterative and sustained collaboration rather than short-term interventions. This highlights the need for longitudinal professional development programs rather than one-off workshops.

Within the vocational education setting, the stakes of technology integration are particularly high. Teachers are expected not only to use digital tools effectively but also to align them with authentic industrial practices. Collaboration proved instrumental in accelerating this

alignment: groups of teachers specializing in similar occupational fields shared industry-standard tools (e.g., CAD software, CNC simulation, LMS with competency-based assessment) and jointly adapted them into teaching scenarios. At the same time, contextual challenges emerged, such as dependence on laboratory infrastructure, disparities in technological resources, and variations in vocational curricula across institutions. These contextual factors suggest that while collaboration is universally beneficial, its impact is contingent upon structural and institutional support.

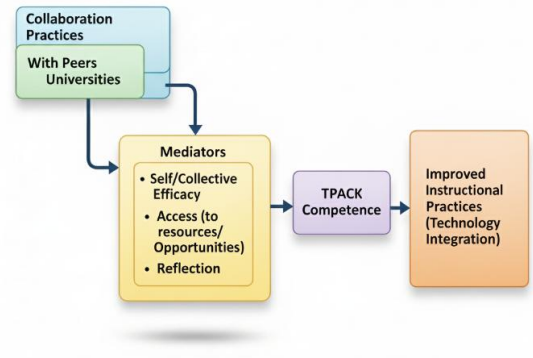

Fig 4. Collaboration Practices in Technological Integration

The findings carry several practical implications. At the school level, vocational institutions should allocate protected time for teacher collaboration, provide incentives for participation, and invest in the necessary infrastructure to support technological integration. At the policy level, formal recognition of collaborative professional development within teacher evaluation and career progression frameworks could further institutionalize these practices. Moreover, partnerships with industry stakeholders should be embedded into collaborative initiatives to ensure that the technologies integrated into classrooms remain authentic and up-to-date.

Future studies should build on this work in several ways. First, including student learning outcomes as dependent variables will clarify whether improvements in teachers' TPACK translate into tangible benefits for learners. Second, quasi-experimental or randomized controlled designs would strengthen causal inferences. Third, advanced statistical modeling such as structural equation modeling or hierarchical linear modeling could test the mediating roles of self-efficacy and collective efficacy. Fourth, reporting effect sizes and confidence intervals alongside p-values will enhance interpretability of findings. Finally, longitudinal follow-ups are needed to assess the sustainability of collaborative impacts over time.

In summary, this study demonstrates that teacher collaboration serves as a powerful driver of meaningful technological integration in vocational education. By creating opportunities for shared practice, reflective dialogue, and joint innovation, collaboration enhances not only technological skills but also the pedagogical capacity to use those skills effectively. While contextual constraints and methodological limitations remain, the findings underscore the transformative potential of structured, well-supported collaboration as a professional development strategy in the digital era.

5. Conclusions

This study investigated the collaborative practices and barriers to technology integration among 30 vocational teachers in Yogyakarta, Indonesia, with a focus on the TPACK framework. The findings revealed that while a considerable proportion of teachers actively engage in collaborative practices to strengthen their TPACK, participation remains uneven and often dependent on individual or school-level initiatives rather than systematic institutional structures. Time constraints, limited access to technological resources, and curriculum misalignment were identified as the most prominent barriers to consistent technology integration. More than half of the teachers reported experiencing barriers frequently, reflecting the continuing challenges faced in vocational education contexts.

Theoretically, this study contributes to the literature by highlighting the central role of collaboration not only among teachers but also between vocational schools and higher education institutions. This cross-institutional collaboration emerges as a novel pathway for strengthening TPACK development, offering vocational teachers access to advanced technological expertise, mentoring opportunities, and joint curriculum innovation. Practically, the findings underscore the need for schools and policymakers to institutionalize collaboration through professional learning communities (PLCs), continuous professional development (CPD), and curriculum flexibility that embeds technology authentically into pedagogy and content.

From a policy perspective, the results point to the importance of designing multilevel interventions that combine infrastructure provision, structured collaboration time, and sustained partnerships with universities. Such systemic support is necessary to reduce inequities in technology adoption and to ensure that integration is not left solely to teacher initiative.

The study is not without limitations. The sample was restricted to vocational teachers in Yogyakarta, which may limit the generalizability of the findings to other regions. Additionally, the cross-sectional design does not capture long-term changes in collaboration or technology adoption. Future research should adopt comparative studies across provinces, explore longitudinal designs to trace TPACK development over time, and examine the impact of structured university–school collaboration models on vocational teacher competence.

In conclusion, while vocational teachers in Yogyakarta are making meaningful progress in collaborative practices for TPACK development, significant barriers persist that require systemic solutions. Embedding collaboration into institutional structures, expanding partnerships with universities, and ensuring sustained professional development represent key strategies to bridge gaps and prepare vocational education to meet the demands of the digital era.

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