Predictors and Barriers to TPACK Implementation among Secondary School Teachers Trained at Haramaya University, Eastern Ethiopia

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Received: 25 September 2025; Accepted:1 October 2026

Abstract: *This study examined teachers' implementation of the Technological Pedagogical Content Knowledge (TPACK) framework, identified barriers to its effective implementation, and examined the relationships between TPACK domains and classroom technology integration. A quantitative survey research design was employed. Primary data were collected from in-service teachers who participated in Continuing Professional Development (CPD) training at Haramaya University in the Eastern Region using a structured questionnaire adapted from validated TPACK instruments. The study was restricted to in-service teachers who had participated in the CPD program and completed the survey. Descriptive statistics (frequency, percentage, mean, and standard deviation) and inferential statistics (Pearson's correlation and multiple linear regression) were used to analyze the data. The findings revealed that participants demonstrated moderate levels of TPACK implementation, with Pedagogical Content Knowledge being the most strongly implemented domain, while Technological Content Knowledge emerged as the strongest predictor of TPACK implementation. Major barriers included inadequate technological infrastructure, insufficient professional development, limited instructional time, large class sizes, and low digital competence. The study concludes that theoretical awareness alone is insufficient for effective technology integration without sustained institutional support and practice-oriented professional development. It is recommended that teacher education institutions redesign CPD programs to strengthen integrated TPACK competencies, improve technological infrastructure, and provide continuous, context-specific professional learning opportunities to promote meaningful technology-enhanced teaching.*

Keywords: *Digital Literacy, Haramaya University, Psychology, Technology Integration, TPACK*

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Introduction

The Technological Pedagogical Content Knowledge (TPACK) framework evolved from Shulman's (1986) concept of Pedagogical Content Knowledge (PCK), which argues that effective teaching requires more than mastery of subject matter (Content Knowledge [CK]) and instructional methods (Pedagogical Knowledge [PK]). Instead, teachers need an integrated understanding of how pedagogy transforms subject content into meaningful learning experiences. Recognizing the growing role of educational technology, Pierson (2001) extended this concept by introducing Technological Pedagogical Content Knowledge (TPCK), describing technology as a means of enhancing pedagogical content knowledge. Niess (2005) further emphasized that teachers should view technology as an integral component of instruction, requiring continuous adaptation to learners, curriculum, and classroom contexts rather than treating it as an isolated technical skill (Angeli & Valanides, 2013).

Building on these foundations, Mishra and Koehler (2006) formally developed the TPACK framework, integrating Technological Knowledge (TK) with CK and PK and identifying the intersecting domains of Pedagogical Content Knowledge (PCK), Technological Content Knowledge (TCK), and Technological Pedagogical Knowledge (TPK), which collectively constitute TPACK. Their design-based approach highlighted that effective technology integration depends on the simultaneous interaction of technology, pedagogy, and content. Likewise, Barnett and Hodson (2001) advocated authentic teacher preparation through collaborative lesson design and reflective practice. Between 2006 and 2012, numerous intervention studies involving pre-service teachers, in-service teachers, and university instructors demonstrated that TPACK-oriented professional development enhanced teachers' instructional competencies, although many studies relied on qualitative or mixed-methods designs with relatively small samples (Angeli & Valanides, 2013; Aydın et al., 2017). During this period, studies also showed that teachers generally possessed strong

CK and TK but comparatively weaker PCK and TCK, indicating persistent challenges in integrating technology effectively with pedagogy and subject content.

The framework has continued to evolve. Mishra and Koehler (2008) standardized the term TPACK, while Mishra (2019) later introduced Contextual Knowledge (XK), expanding the framework to acknowledge the influence of institutional policies, infrastructure, leadership, culture, and resource availability on technology integration. Recent evidence further confirms that collaborative professional learning approaches, including lesson study, co-design, classroom implementation, and reflective practice promote stronger TPACK development than traditional workshop-based training. However, many researchers argue that TPACK assessment should extend beyond self-report surveys to include authentic measures such as lesson planning, classroom observation, concept mapping, and micro-teaching to capture teachers' actual instructional competence (Irwanto et al., 2022; Bruno et al., 2024).

In Ethiopia, recent studies indicate growing interest in applying the TPACK framework to improve technology-enhanced instruction. Teachers' digital competence has been positively associated with classroom technology integration and improved instructional practices (Demissie et al., 2022). Nevertheless, Ethiopian secondary school teachers generally demonstrate stronger content and pedagogical knowledge than technological knowledge, limiting meaningful ICT integration (Mihretab et al., 2022). Although the government has invested on ICT infrastructure and technology-based instructional initiatives, effective classroom implementation remains constrained by inadequate technological resources, limited technology-focused professional development, insufficient mentoring, and inconsistent institutional support.

Studies further reveal that teachers who receive sustained, subject-specific TPACK-oriented training demonstrate greater competence in integrating technology into teaching than those participating in general ICT training. These findings suggest that successful technology integration requires continuous professional development that combines content knowledge, pedagogy, and technology within authentic classroom contexts. Consequently, the TPACK framework provides a comprehensive theoretical foundation for understanding and improving teachers' technology integration practices in Ethiopian secondary schools while addressing the contextual factors that influence effective instructional implementation.

Recent studies indicate that Ethiopia's Continuous Professional Development (CPD) program has made important contributions to strengthening teachers' pedagogical competence and subject matter knowledge; however, technology-oriented professional learning remains insufficiently emphasized. Although the national CPD framework promotes instructional improvement, its implementation is often characterized by generic training content, inadequate digital infrastructure, limited technology integration, weak institutional support, and insufficient follow-up coaching, which constrain teachers' ability to develop and apply Technological Pedagogical Content Knowledge (TPACK) in classroom practice (Berhanu, 2024; Mekonnen et al., 2025; Tiruneha et al., 2025). Moreover, recent evidence on TPACK implementation in Ethiopian teacher education has primarily examined institutional practices and contextual challenges rather than investigating how teachers who have completed CPD programs translate acquired competencies into effective technology-integrated instruction. Consequently, there remains a significant empirical gap in identifying the predictors and barriers influencing TPACK implementation among secondary school teachers trained through the Haramaya University CPD program. Addressing this gap is essential for generating context-specific evidence that can inform the redesign of CPD toward technology-integrated, sustainable, and evidence-based

professional learning aligned with the demands of 21st-century education.

Statement of the Problem

Empirical evidence indicates that although teachers generally demonstrate strong content knowledge (CK) and pedagogical knowledge (PK), they continue to experience difficulties integrating technology effectively into teaching and learning. Studies consistently report lower competence in technological knowledge (TK), technological pedagogical knowledge (TPK), technological content knowledge (TCK), and the comprehensive TPACK domain than in traditional teaching competencies (Ismael et al., 2023; Sun & Sukor, 2023). While many educational systems have expanded access to digital technologies, professional development programs often emphasize basic ICT literacy rather than technology-enhanced pedagogy that supports subject-specific instruction.

Similar challenges have been reported in Ethiopia and other developing countries, where Continuous Professional Development (CPD) primarily focuses on general digital skills, with limited attention to helping teachers integrate technology, pedagogy, and content within authentic classroom contexts (Thy et al., 2023). Furthermore, researchers continue to debate the conceptual boundaries and measurement of TPACK, as most studies rely on self-reported perceptions rather than classroom observations or performance-based assessments, resulting in inconsistent findings regarding teachers' actual competencies (González et al., 2023; Sun & Sukor, 2023).

Although the existing literature has substantially advanced understanding of TPACK, the field remains dynamic because educational technologies, digital pedagogies, and curriculum demands continue to evolve rapidly. Consequently, findings from earlier studies cannot adequately explain teachers' readiness to integrate emerging

technologies or the contextual factors influencing technology-enhanced teaching in different educational settings. Recent reviews emphasize that TPACK development is highly dependent on contextual variables such as institutional support, school leadership, infrastructure, technology access, and the quality of CPD programs, all of which vary considerably across countries and educational systems (Bruno et al., 2024; Irwanto et al., 2022). In Ethiopia, empirical studies remain limited, fragmented, and largely descriptive, focusing primarily on teachers' general ICT competence or technology use rather than examining the combined influence of individual and institutional factors that facilitate or hinder TPACK implementation. Moreover, little evidence exists regarding whether CPD initiatives effectively prepare teachers to integrate technology into subject-specific classroom instruction, indicating that the empirical research gap remains both relevant and timely.

Against this background, the present study investigates the predictors and barriers of TPACK implementation among secondary school teachers who participated in the Haramaya University Continuous Professional Development (CPD) program. Unlike previous Ethiopian studies that mainly described teachers' technology use or digital competence, this study examines how individual competencies, institutional support, and CPD experiences jointly influence TPACK implementation in real classroom settings. Focusing on teachers trained through Haramaya University's CPD program, which started in 2024 and continues to date, provides context-specific evidence that reflects the realities of Ethiopian secondary school education and addresses the limited empirical knowledge regarding the effectiveness of technology-oriented professional development. The findings are expected to contribute to the refinement of CPD policies and practices by identifying evidence-based strategies that strengthen technology integration, enhance teachers' instructional competence, and improve the quality of secondary education in Ethiopia.

Basic Research Questions

This study seeks to address the following research questions:

a. What is the current level of teacher educators' competencies across the TPACK domains for integrating technology into teaching in Ethiopian secondary school teacher education?
b. What institutional and individual factors facilitate or hinder teacher educators' effective implementation of the TPACK framework in their teaching practices?
c. To what extent do the TPACK domains: CK, PK, TK, PCK, TCK, TPK, and overall TPACK, significantly predict teacher educators' implementation of the TPACK framework in Ethiopian secondary school teacher education?

H_o: There is no statistically significant relationship between teachers' CK, PK, TK, PCK, TCK, and TPK, and their overall TPACK implementations.

Definitions of Key Terms

In-Service Teachers refers to practicing teachers who are currently employed in educational institutions and participate in continuous professional learning activities aimed at improving their instructional knowledge, skills, and professional competencies (European Commission, 2022). Continuous professional development is particularly important for enabling teachers to adapt to evolving digital learning environments and effectively integrate technologies into classroom practices (UNESCO, 2022). In-service teachers' technology integration competency depends not only on access to technological resources but also on opportunities for training, institutional support, and ongoing professional learning (Rizvi et al., 2022; Scherer et al., 2020). In this study, in-service teachers are operationally defined as currently practicing school teachers who participate in professional

development activities and apply acquired technological knowledge and skills to support teaching, learning, and assessment processes.

Teacher Educators are higher education professionals responsible for preparing, mentoring, and supporting prospective and practicing teachers through teacher education programs, professional development, research, and instructional supervision (Lunenberg et al., 2020). Beyond transmitting pedagogical knowledge, teacher educators serve as professional role models whose own instructional practices influence how future and practicing teachers perceive and apply educational technologies (Tondeur et al., 2021). Therefore, developing teacher educators' capacity to integrate technology is considered essential for promoting sustainable digital transformation in teacher education institutions (UNESCO, 2022). In this study, teacher educators are operationally defined as university academic staff members engaged in teacher preparation and professional development activities who model, teach, and support technology-enhanced instructional practices.

Technology Integration refers to the purposeful use of digital technologies, including digital devices, applications, online resources, and learning platforms, as integral components of teaching, learning, assessment, and classroom management rather than as supplementary tools (UNESCO, 2022). Effective technology integration occurs when teachers select and apply appropriate technologies to enhance pedagogical practices, promote active learning, facilitate collaboration, and support students' construction of knowledge (Scherer et al., 2020; Tondeur et al., 2021). In this study, technology integration is operationally defined as the extent to which teacher educators and in-service teachers utilize digital technologies for instructional planning, delivery, assessment, communication, and the creation of technology-enhanced learning environments.

Technology Integration Competency refers to teachers' integrated knowledge, skills, attitudes, and abilities required to meaningfully

select, adapt, and use technologies to support effective teaching and learning (UNESCO, 2022). It extends beyond technical proficiency by emphasizing the interaction among technological knowledge, pedagogical knowledge, and content knowledge, as conceptualized in the Technological Pedagogical Content Knowledge (TPACK) framework (Koehler et al., 2021). Recent research emphasizes that teachers' technology integration competency includes the capacity to evaluate digital resources, design technology-supported learning experiences, implement technology-mediated instruction, and use digital assessment strategies effectively (Scherer et al., 2020; Tondeur et al., 2021). In this study, technology integration competency is operationally defined as teacher educators' and in-service teachers' self-perceived competence in technological knowledge, pedagogical application of technology, digital resource management, technology-supported assessment, and the design of technology-enhanced instructional practices.

Review of Related Literature

This section reviews the theoretical and empirical literature relevant to the Technological Pedagogical Content Knowledge (TPACK) framework and its implementation in educational settings. Specifically, it synthesizes recent studies on the conceptual foundations of TPACK, teachers' technology integration competencies, and the contributions of the TPACK knowledge domains to effective technology-enhanced teaching. The review also critically examines contemporary evidence on TPACK implementation and identifies existing knowledge gaps, particularly in teacher education within developing countries. By integrating current empirical findings and theoretical perspectives, this review establishes the conceptual foundation for the present study and justifies the investigation of the predictive roles of the TPACK domains in explaining teacher educators' implementation of the TPACK framework in Ethiopian secondary school teacher education.

Technological Pedagogical Content Knowledge (TPACK) Framework

Technology integration has become a fundamental expectation of effective teaching in the digital era. Consequently, the Technological Pedagogical Content Knowledge (TPACK) framework has emerged as one of the most widely accepted theoretical models for explaining how teachers integrate technology into teaching and learning. The framework conceptualizes teachers' professional knowledge as the interaction among Content Knowledge (CK), Pedagogical Knowledge (PK), Technological Knowledge (TK), Pedagogical Content Knowledge (PCK), Technological Content Knowledge (TCK), Technological Pedagogical Knowledge (TPK), and the integrated TPACK construct. Rather than viewing technology competence as an isolated skill, TPACK emphasizes the dynamic integration of these knowledge domains to facilitate meaningful instructional practices (Schmid et al., 2024; Aqib et al., 2024).

Recent reviews indicate that TPACK has become the dominant theoretical framework for investigating teachers' digital competencies across diverse educational contexts. Although numerous empirical studies have validated the usefulness of the framework, scholars argue that future research should focus more explicitly on understanding how the individual knowledge domains contribute to teachers' technology integration practices. Moreover, researchers recommend strengthening the conceptualization and measurement of TPACK to improve its explanatory power in educational research (Schmid et al., 2024).

TPACK and Technology Integration Competencies

Teachers' technology integration competence extends beyond their ability to operate digital tools. It encompasses the ability to select, adapt, and implement technologies that effectively support pedagogical strategies and subject-matter instruction. Recent empirical evidence consistently demonstrates that teachers possessing higher levels of TPACK exhibit greater confidence, instructional innovation, digital

competence, and effectiveness in technology-enhanced teaching than those with lower TPACK competencies (Ye et al., 2024; Luo & Zou, 2024). Similarly, systematic reviews have shown that each TPACK domain contributes uniquely to successful technology integration. CK enables teachers to organize disciplinary knowledge effectively, PK supports instructional design and classroom management, while TK provides the technological skills necessary for digital instruction. The intersecting domains (PCK, TCK, and TPK) facilitate the pedagogically appropriate use of technology within specific content areas, whereas the integrated TPACK construct reflects teachers' overall readiness to design meaningful technology-supported learning experiences (Aqib et al., 2024).

Furthermore, recent meta-analytic evidence suggests that professional learning interventions grounded in the TPACK framework significantly improve teachers' technology integration competencies across educational settings. Such interventions strengthen teachers' knowledge integration and positively influence instructional practices, indicating that TPACK remains an effective framework for guiding teacher education and professional development initiatives (Fabian et al., 2024).

Theoretical Perspectives on TPACK Implementation

Contemporary TPACK research emphasizes that technology integration is influenced not only by teachers' technological knowledge but also by the interaction among pedagogical expertise, disciplinary understanding, and instructional decision-making. Consequently, TPACK is increasingly viewed as a dynamic and context-dependent construct that develops through authentic teaching experiences and continuous professional learning (Schmid et al., 2024). Recent literature also suggests that contextual variables, including institutional support, digital infrastructure, leadership, school culture, and access to technological resources, may influence teachers' opportunities to

implement TPACK effectively. Nevertheless, these contextual variables primarily function as enabling conditions rather than constituting components of the TPACK framework itself. Accordingly, studies whose primary objective is to examine the predictive contributions of the seven TPACK domains should remain conceptually anchored within the original TPACK framework while acknowledging contextual influences as supporting conditions (Aqib et al., 2024; Schmid et al., 2024)

Synthesis of the Literature and Research Gap

The reviewed literature consistently identifies TPACK as a robust theoretical framework for understanding teachers' technology integration competencies. Although many recent studies have investigated digital competence, teacher readiness, professional development, and contextual influences on technology integration, comparatively fewer studies have empirically examined the predictive contributions of the individual TPACK domains (CK, PK, TK, PCK, TCK, TPK, and overall TPACK) toward teachers' implementation of technology-integrated instruction within a unified explanatory model (Fabian et al., 2024; Schmid et al., 2024). Moreover, most empirical investigations have concentrated on preservice teachers or higher education settings, with limited attention given to teacher educators in developing countries. In Ethiopia, empirical evidence regarding teacher educators' TPACK competencies and their contribution to technology integration remains scarce. Addressing this gap, the present study employs the TPACK framework to examine teacher educators' competencies across the seven knowledge domains and to determine the extent to which these domains predict TPACK implementation in secondary school teacher education. The findings are expected to contribute to both the theoretical advancement of the TPACK framework and evidence-based strategies for strengthening technology integration in teacher education.

Summary of the Review of Related Literature

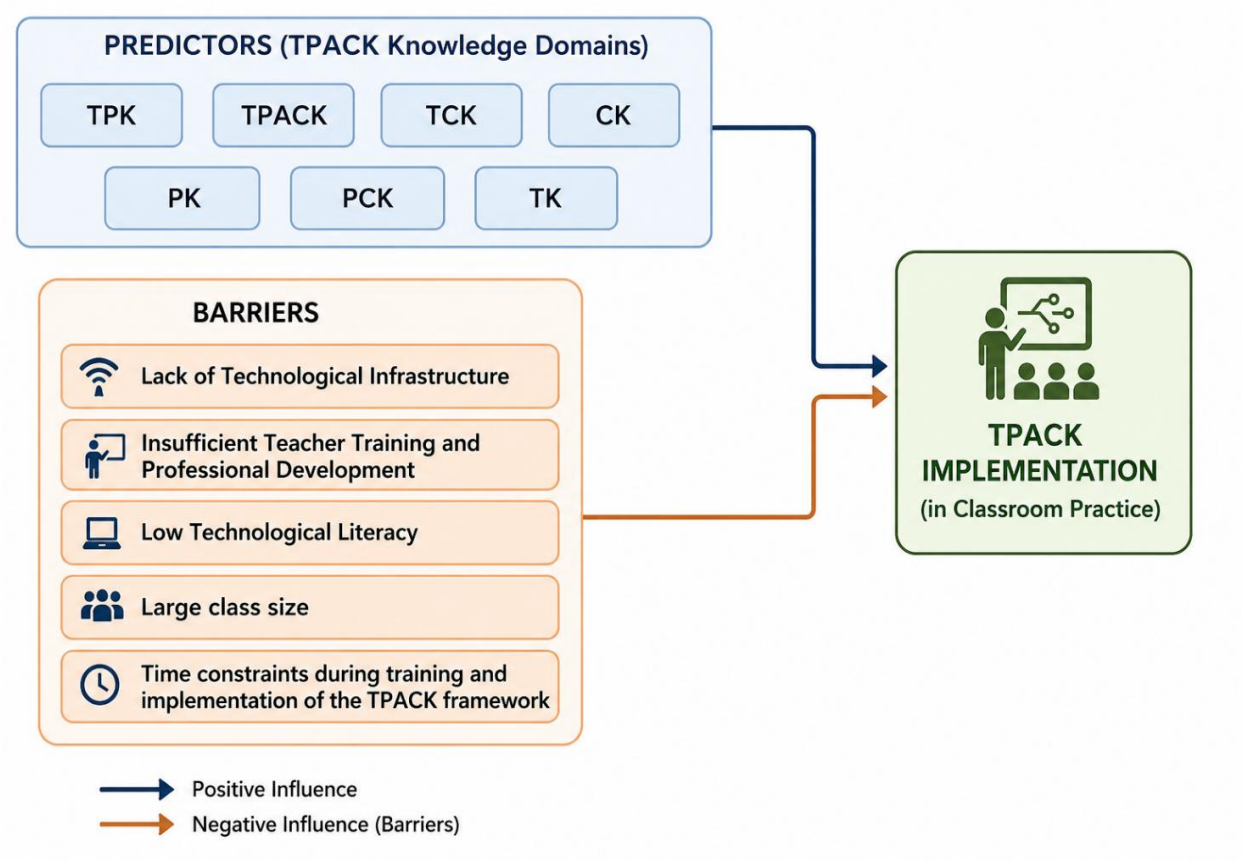
The reviewed literature demonstrates that the Technological Pedagogical Content Knowledge (TPACK) framework provides a comprehensive and well-established theoretical foundation for understanding teachers' effective integration of technology into teaching and learning. The literature consistently emphasizes that successful technology integration depends on the dynamic interaction among content knowledge, pedagogical knowledge, technological knowledge, and their interrelated domains rather than on technological skills alone. Teachers with stronger TPACK competencies are more likely to design learner-centered instruction, select appropriate digital tools, and implement technology in ways that enhance teaching effectiveness and student learning. The review further indicates that TPACK has become one of the most widely adopted frameworks for evaluating technology integration competencies in teacher education and professional practice.

The literature also reveals that, although substantial progress has been made in understanding technology integration, empirical evidence examining the predictive contributions of the individual TPACK domains to technology implementation remains relatively limited, particularly in developing-country contexts. Existing studies have primarily focused on teachers' digital readiness, technology integration competencies, and contextual conditions, while comparatively fewer investigations have examined how the seven TPACK domains collectively explain the implementation of the framework. Furthermore, research involving teacher educators in Ethiopian secondary school teacher education is scarce. These gaps underscore the need for the present study, which seeks to examine teacher educators' competencies across the TPACK domains and determine the extent to which these domains predict the implementation of the TPACK framework, thereby contributing to both theory and practice in technology-enhanced teacher education.

Conceptual Framework

The conceptual framework for this study is grounded in the Technological Pedagogical Content Knowledge (TPACK) framework developed by Mishra and Koehler (2006), which posits that effective technology integration in teaching results from the interaction of teachers' technological, pedagogical, and content knowledge. Accordingly, this study conceptualizes the seven TPACK knowledge domains—Technological Knowledge (TK), Pedagogical Knowledge (PK), Content Knowledge (CK), Pedagogical Content Knowledge (PCK), Technological Content Knowledge (TCK), Technological Pedagogical Knowledge (TPK), and the comprehensive TPACK construct—as the primary predictor variables influencing teachers' implementation of TPACK in classroom practice. Teachers with stronger competencies across these interconnected knowledge domains are expected to demonstrate greater capacity to design, deliver, and evaluate technology-enhanced instruction that supports meaningful student learning.

The framework further recognizes that successful TPACK implementation is influenced not only by teachers' knowledge but also by contextual barriers that may constrain technology integration. Specifically, lack of technological infrastructure, insufficient teacher training and professional development, low technological literacy, large class size, and time constraints during training and classroom implementation are conceptualized as barriers that may hinder the effective application of TPACK. Drawing on the TPACK framework and recent empirical evidence, the study assumes that TPACK implementation is determined by the combined influence of teachers' knowledge domains and institutional or contextual conditions. This conceptual framework therefore provides the theoretical basis for examining the predictive relationships between the independent variables and TPACK implementation among secondary school teachers who participated in the Haramaya University Continuous Professional Development (CPD) program in Eastern Ethiopia.



Research Methodology

A descriptive survey research design was employed to collect quantitative data from participants (N = 350) using stratified random sampling. This design is commonly used in TPACK studies to gather data on teachers' self-perceptions and practices regarding technology integration. It allows researchers to describe the current status of teachers' TPACK competencies, including TK, PK, CK, and their intersections, without manipulating variables. This approach provides a snapshot of teachers' perceived readiness to integrate technology into

their instructional practices. To implement this design, the researcher used a structured questionnaire comprising Likert-scale items measuring all seven TPACK components.

This methodological approach was considered effective for informing policy decisions, designing targeted professional development programs, and guiding curriculum reform aimed at enhancing technology integration in secondary education. Overall, the descriptive survey design offered a structured and practical means of assessing the state of TPACK implementation among secondary school teachers in Ethiopia. The target population included teachers from five colleges: The College of Education and Behavioral Sciences (CEBS), the College of Natural and Computational Sciences (CoNCS), and the College of Social Sciences and Humanities (CoSSH).

Table 1. *population, sample size, and sampling techniques used in the study*

No.	Colleges	Departments	Population (Ni)	Sample (n_i = 14%)
1.	CoAES	Agriculture	200	28
		NRM	28	5
		Total	228	33
2.	CoBE	Acct & Fin	14	4
		Economics	233	33
		Total	247	37
3.	CoCI	ICT	246	34
4.	CoNCS	Biology	165	24
		Chemistry	158	22
		Mathematics	171	25
		Physics	153	21
		Total	647	92
5.	CoSSH	Civic Educ	242	35
		English	169	24
		Geography	342	48
		History	332	47
		Total	1085	154
	Grand Total		2453	350

Both stratified and systematic random sampling techniques were employed. Stratified random sampling was used to create homogeneous strata by

accounting for key differences in the population, such as colleges, departments, and population sizes, which varied across the institution. This approach helped the researcher reduce population heterogeneity. Within each stratum, systematic random sampling was applied to select participants. After alphabetically arranging the target population within each stratum, the sampling interval **(**Kth value**)** was calculated and used to systematically draw the required sample.

Primary data were collected through questionnaires administered to in-service teachers undergoing training at Haramaya University in Eastern Ethiopia. The questionnaire consisted of two sections. The first section collected demographic information from participants, while the second contained 70 items designed to assess Ethiopian secondary school teachers' perceptions of TPACK training at Haramaya University. A structured questionnaire using a five-point Likert scale, adopted from Sahin (2011), was utilized. Items were rated as follows: 1 = Strongly Disagree (SDA), 2 = Disagree (DA), 3 = Undecided (UND), 4 = Agree (A), and 5 = Strongly Agree (SA). The instrument was pilot-tested with 40 in-service teachers who were not included in the main sample. Their responses were used to assess the reliability and validity of the questionnaire. Reliability was evaluated using Cronbach's alpha coefficient, which yielded an overall score of .90, indicating excellent internal consistency. Based on the pilot results, the researcher revised several items, particularly adjusting technical terms and phrases that appeared unclear or difficult for participants to understand.

Table 2. *Reliability scores for the overall TPACK instrument and its individual components*

No	TPACK Domain	Number of Items	Alpha Values
1.	Content Knowledge (CK)	10	.82
2.	Pedagogy Knowledge (PK)	10	.92
3.	Technology Knowledge (TK)	10	.89
4.	Pedagogical Content Knowledge (PCK)	10	.91
5.	Technological Content Knowledge (TCK)	10	.85
6.	Technological Pedagogical Knowledge (TPK)	10	.93
7.	Technological Pedagogical Content Knowledge (TPACK)	10	.85
	Overall reliability	70	.90

Source: Survey, 2025

Table 2 shows that the Cronbach's alpha coefficient for TPK was the highest among all TPACK components, at .93, indicating that this component demonstrated strong internal consistency and played a significant role in the study. In contrast, the lowest alpha value was observed for CK, which scored .82, still within the acceptable range for reliability but lower than the other six components. The collected data were analyzed using descriptive statistics, including frequencies, percentages, means, and standard deviations. These analyses helped the researcher identify the TPACK domains in which teachers felt confident, as well as areas where additional support or training may be needed. In addition to descriptive statistics, a range of inferential statistical methods was employed, including correlation analysis and multiple linear regression. These methods were used to examine relationships, group differences, the contribution of independent variables to dependent variables, and the variance in TPACK levels explained by teacher demographics (e.g., age, gender, teaching experience, and educational qualifications).

The questionnaire used in the present study was adopted through a rigorous and systematic instrument adaptation procedure to ensure its

conceptual relevance, contextual appropriateness, and psychometric adequacy for the target population. Initially, an extensive review of the existing literature and previously validated instruments related to the study constructs was conducted to identify suitable measurement items. The selected items were carefully examined for theoretical alignment with the study objectives and adapted to reflect the Ethiopian secondary school teacher education context without altering their underlying constructs. The adapted instrument was subsequently evaluated by experts in educational technology, teacher education, and educational measurement to establish content validity, clarity, cultural appropriateness, and contextual suitability. Based on expert feedback, necessary modifications were made to improve the wording, relevance, and comprehensibility of the items.

Following the expert review process, the revised questionnaire was pilot-tested with a sample comparable to the target participants to evaluate item clarity, response patterns, and preliminary reliability. The pilot results informed further refinements, including minor revisions in item wording and organization to enhance the accuracy and usability of the instrument. The final version of the questionnaire was then administered to the main sample after confirming acceptable reliability and validity evidence. These systematic procedures ensured that the adopted instrument maintained the theoretical integrity of the original measures while being appropriately contextualized for the current research setting, thereby strengthening the credibility and trustworthiness of the study findings.

Assumption Testing Before Statistical Analysis

Assumptions included homoscedasticity, constant variance across all values of the independent variable, and the absence of significant outliers that could distort the correlation coefficient. Moreover, both variables were expected to be approximately normally distributed, particularly for significance testing. In addition to the correlation

analysis, HMLR was conducted to assess the predictive power of the independent variables. Before the regression analysis, assumptions of normality, linearity, and homoscedasticity were evaluated. A visual inspection of standardized residuals using histograms and Q–Q plots indicated approximate normal distribution. Linearity was confirmed through a residuals-versus-fitted-values plot, which showed a random scatter around zero with no clear patterns. The Durbin–Watson statistic was .532, suggesting no major concerns with residual autocorrelation. Variance inflation factors (VIFs) ranged from 1.412 to 2.512, with all tolerance values exceeding .40, indicating no multicollinearity issues. Had VIFs exceeded 5 or tolerance values dropped below .10, corrective measures such as variable elimination or principal component analysis (PCA) would have been considered. These results confirmed that the data satisfied the assumptions necessary for valid differences, correlation, and regression analyses.

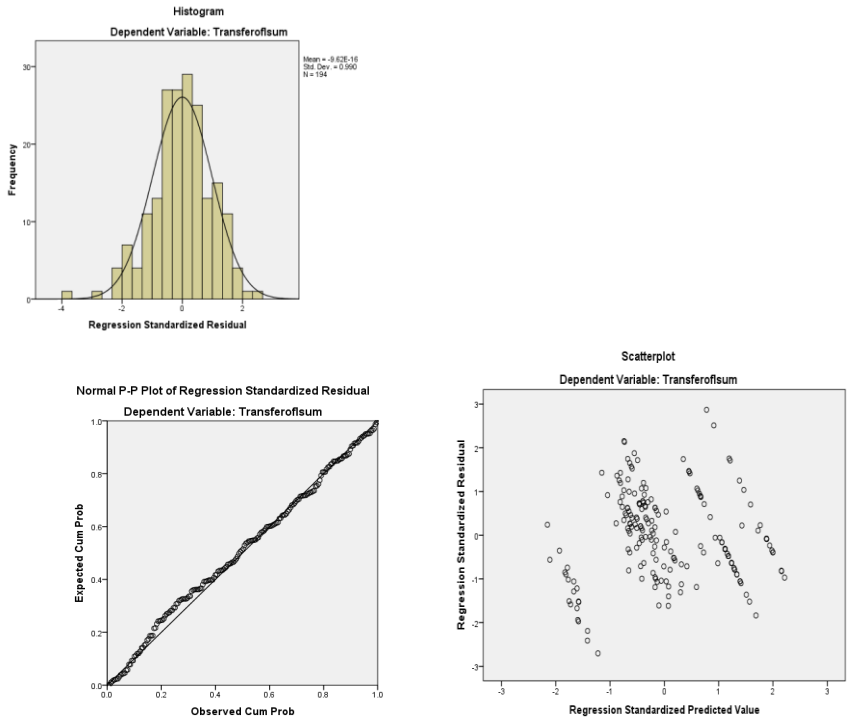


Fig.1. Normality and linearity test

Table 3. *Test of Homogeneity of Variances of teachers' level of education*

	Levene Statistic	df1	df2	Sig.
Technological Pedagogical Knowledge (TPK)	1.503	4	345	.201
Technological Pedagogical Content Knowledge (TPACK)	2.212	4	345	.067
Technological Content Knowledge (TCK)	1.435	4	345	.222
Content Knowledge (CK)	.808	4	345	.521
Pedagogical Knowledge (PK)	1.415	4	345	.228
Pedagogical Content Knowledge (PCK)	1.820	4	345	.124
Technological Knowledge (TK)	1.333	4	345	.230

The assumption of homogeneity of variances was assessed using Levene's Test before conducting the one-way ANOVA. For example, the test was not statistically significant for TPAK, F (4, 345) = 1.503, p = .201, indicating that the variances across educational qualification groups (BA, BSc, MA, MSc, and PhD) were equal. Similarly, Levene's Test results for all seven TPACK domains revealed no significant violations of the equal variances assumption. These results support the use of standard one-way ANOVA, as the assumption of homogeneity of variances was met. Had Levene's Test indicated a significant result, suggesting unequal variances, an alternative method such as Welch's ANOVA would have been used instead.

Results

A total of 374 questionnaires were distributed to in-service teachers, 100 females and 274 males, who participated in a three- to four-day pedagogy training program at Haramaya University. Of these, 95 female and 255 male participants completed and returned the questionnaires, resulting in 350 valid responses. This yielded an overall return rate of 93.58%, with a response rate of 95% for female participants and 93.07% for male participants. These 350 responses were deemed adequate for further statistical analysis. The distribution of respondents by college, in descending order, was as follows: College of Social Sciences and Humanities (CoSSH) – 44%, College of Natural and Computational Sciences (CoNCS) – 26.29%, College of Business and Economics (CoBE) – 10.57%, College of Computing and Informatics (CoCCI) – 9.71%, and College of Agriculture and Environmental Sciences (CoAES) – 9.43%. The researcher considered the sample size sufficient to address the study's objectives.

The return rate was calculated by dividing the number of completed questionnaires (n = 350) by the total number distributed (n = 374) and multiplying by 100, yielding 93.58%. Gender-specific response rates were similarly calculated: 95 completed responses from 100 distributed to females (95%), and 255 from 274 distributed to males (93.07%). To

ensure a high return rate, questionnaires were administered in person at the end of the training sessions, allowing participants adequate time to respond on-site. This approach minimized the likelihood of non-responses and improved data completeness. Additionally, clear instructions and assurances of confidentiality were provided to encourage honest and thoughtful participation.

Research Question 1

What competencies do teacher educators currently possess regarding the integration of technology into teaching in Ethiopian secondary schools?

Table 4. *In-service teachers' perceived competencies in integrating TPACK into their instructional practices*

No.	Variables	Frequencies	Percent (%)	Cumulative (%)
1.	Basic Digital Literacy	115	32.9	32.9
2.	Theoretical Awareness	157	44.9	77.7
3.	Positive Attitudes Toward Technology	78	22.3	100.0
	Total	350	100.0	

In the context of Ethiopian secondary schools, teacher educators were found to possess varying levels of competency in three key areas related to technology integration: basic digital literacy, theoretical awareness, and attitudes toward technology. As shown in Table 5, most participants, 157 (44.9%), reported being most competent in theoretical awareness. Some had been introduced to the TPACK framework and its integration principles during pre-service or in-service training. Meanwhile, 115 participants (32.9%) indicated competency in basic digital literacy, demonstrating skills in using standard productivity tools (e.g., Microsoft Office), email, and conducting online searches.

Lastly, 78 participants (22.3%) reported competency in developing positive attitudes toward technology, with many expressing a willingness to use technology and recognizing its potential to enhance student learning.

Research Question 2

What are the factors that influence teacher educators' integration of technology into teaching?

Table 5. *In-service teachers' perceptions of the factors affecting the implementation of TPACK in Ethiopian secondary school classrooms*

No	Perceived Factors	Frequency	Percent	Cumulative (%)	Rank
1.	Lack of Technological Infrastructure	110	31.53	31.53	1st
2.	Insufficient Teacher Training and Professional Development	73	20.72	52.25	3rd
3.	Low Technological Literacy	41	11.71	63.96	5th
4.	Large class-size	76	21.62	85.58	2nd
5.	Time constraints during training and implementation of the TPACK framework	50	14.42	100.0	4th
	Total	350	100.0		

Table 5 shows that the five most significant barriers to teachers' implementation of the TPACK framework in Ethiopian secondary schools were lack of technological infrastructure (31.53%), large class sizes (21.62%), insufficient teacher training and professional development (20.72%), time constraints during training and implementation (14.42%), and low technological literacy (11.71%). These findings underscore systemic challenges that hinder effective technology integration, suggesting an urgent need for targeted investments in digital infrastructure, scalable teacher training programs, and supportive institutional policies. Addressing these barriers is critical for narrowing the gap between TPACK's theoretical potential and its practical application in resource-constrained educational settings.

H_o: There is no statistically significant relationship between teachers' CK, PK, TK, PCK, TCK, and TPK, and their overall TPACK implementations.

Table 6. *Correlation Matrices between teachers' CK, PK, TK, PCK, TCK, and TPK, and TPACK implementations*

No		1	2	3	4	5	6	7	8
1.	TPACK Implementation	1	.068	.308**	.718**	.644**	.739**	.595**	.449**
2.	TPK		1	-.194**	-.032	-.222**	.029	-.242**	-.395**
3.	TPACK			1	.045	-.141**	.449**	.284**	-.274**
4.	TCK				1	.568**	.398**	.190**	.407**
5.	CK					1	.235**	.297**	.674**
6.	PK						1	.407**	.073
7.	PCK							1	.272**
8.	TK								1

**. *P* < .01.

A Pearson product-moment correlation was conducted to examine the relationship between teachers' TPACK implementation and the individual TPACK domains in secondary schools. The analysis revealed a non-significant and weak positive correlation between TPACK implementation and TPK, $r(348) = .068$, $p > .05$, indicating that lower levels of implementation were not meaningfully associated with stronger TPK. In contrast, a significant positive correlation was found between TPACK implementation and the overall TPACK construct, $r(348) = .308$, $p < .01$, suggesting that teachers with higher TPACK knowledge reported greater levels of implementation. Additionally, significant and positive correlations were observed between TPACK implementation and the following domains: TCK, $r(348) = .718$, $p < .01$;

CK, $r(348) = .644$, $p < .01$; PK, $r(348) = .739$, $p < .01$; PCK, $r(348) = .595$, $p < .01$; and TK, $r(348) = .449$, $p < .01$. These findings indicate that higher levels of TPACK implementation are significantly associated with stronger knowledge in these specific domains.

Research Question 3

To what extent do TPACK domains (CK, PK, TK, PCK, TCK, TPK, and overall TPACK) predict TPACK implementation in secondary schools?

Table 7a. *HMLR Analysis on in-service TPACK implementation in secondary schools*

Model	R	R^2	Adj R^2	SEE	Change Statistics					Durbin-Watson
					ΔR^2	ΔF	df1	df2	Sig. ΔF	
1	.068[a]	.005	.002	32.245	.005	1.617	1	348	.204	
2	.334[b]	.112	.107	30.502	.107	41.908	1	347	.000	
3	.783[c]	.613	.610	20.165	.501	447.994	1	346	.000	
4	.886[d]	.784	.782	15.078	.171	273.855	1	345	.000	
5	.943[e]	.889	.888	10.823	.105	325.569	1	344	.000	
6	.979[f]	.959	.958	6.620	.069	576.478	1	343	.000	
7	.994[g]	.987	.987	3.671	.029	773.742	1	342	.000	.532

a. Predictors: (Constant), TPK, TPACK, TCK, CK, PK, PCK, TK
b. Dependent Variable: TPACK implementation

Table 7a shows that Model 1, which included TPK, explained .5% of the variance in TPACK implementation, F (1, 348) = 1.617, p = .204, indicating a non-significant effect. Model 2, which added TPACK, increased R^2 by 10.7%, F(2, 347) = 21.858, $p < .001$, indicating a significant effect. Model 3, which included TCK, increased R^2 by 50.1%, F (3, 346) = 182.674, $p < .001$, indicating a significant effect. Model 4, incorporating CK, showed a slight increase in R^2 of 17.10%, F

(4, 345) = 313.512, $p < .00$, indicating a significant effect. Model 5, incorporating PK, showed a slight increase in R^2 of 10.50%, F (5, 344) = 551.879, $p < .001$, indicating a significant effect. Model 6, which incorporated PCK, showed a slight increase in R^2 of 6.90%, F(6, 343) = 1325.345, $p < .001$, indicating a significant effect. Finally, Model 7, which added TK, resulted in a slight increase in R^2 of 2.90% but remained significant, F (7, 342) = 3805.855, $p < .001$, indicating a significant effect. Overall, the final model explained 98.70% of the variance in TPACK implementations, indicating that demographics and the seven TPACK domains were significant predictors.

Table 7b. *ANOVA of multiple hierarchical linear egression models predicting TPACK Implementation*

Model		SS	*df*	MS	*F*	*p*
1	Regression	1681.370	1	1681.370	1.617	.204
	Residual	361838.084	348	1039.765		
	Total	363519.454	349			
2	Regression	40672.510	2	20336.255	21.858	<.001
	Residual	322846.945	347	930.395		
	Total	363519.454	349			
3	Regression	222831.866	3	74277.289	182.674	<.001
	Residual	140687.588	346	406.612		
	Total	363519.454	349			
4	Regression	285088.835	4	71272.209	313.512	<.001
	Residual	78430.619	345	227.335		
	Total	363519.454	349			
5	Regression	323224.661	5	64644.932	551.879	<.001
	Residual	40294.793	344	117.136		
	Total	363519.454	349			
6	Regression	348487.977	6	58081.330	1325.345	<.001
	Residual	15031.477	343	43.824		
	Total	363519.454	349			
7	Regression	358911.971	7	51273.139	3805.855	<.001
	Residual	4607.484	342	13.472		
	Total	363519.454	349			

a. Dependent Variable: TPACK implementation
b. Predictors: (Constant), TPK, TPACK, TCK, CK, PK, PCK, TK

The overall regression model was statistically significant, F (7, 342) = 3805.855, p < .001, and explained 98.7% of the variance in TPACK implementations (R^2 = .987). These findings suggest that the combination of these variables significantly predicts teachers' implementation of the TPACK framework in secondary schools.

Table 11c. Coefficients of knowledge domains predicting TPACK implementation (Model 7)

Predictor	B	SE	β	t	p	95% CI LL	95% CI UL	Tolerance	VIF
(Constant)	-1.563	1.834	–	-0.852	.395	-5.170	2.045	–	–
TPK	1.025	.022	.350	46.851	< .001	.982	1.068	.666	1.502
TPACK	1.062	.034	.258	31.438	< .001	.996	1.129	.549	1.820
TCK	1.109	.031	.285	35.657	< .001	1.048	1.170	.579	1.728
CK	1.075	.038	.262	28.171	< .001	1.000	1.150	.429	2.329
PK	.975	.026	.305	37.694	< .001	.924	1.025	.566	1.766
PCK	.922	.024	.277	38.241	< .001	.874	0.969	.708	1.412
TK	.859	.031	.269	27.816	< .001	.798	0.920	.398	2.515

Note. Dependent variable = TPACK implementation. B = unstandardized coefficient; SE = standard error; β = standardized coefficient; CI = confidence interval; LL = lower limit; UL = upper limit; VIF = variance inflation factor. TPK = technological pedagogical knowledge; TPACK = technological pedagogical content knowledge; TCK = technological content knowledge; CK = content knowledge; PK = pedagogical knowledge; PCK = pedagogical content knowledge; TK = technology knowledge.

A hierarchical multiple linear regression analysis was conducted to examine how the seven predictors, TPK, TPACK, TCK, CK, PK, PCK, and TK, contributed to predicting TPACK implementation.

Step 1: TPK accounted for a non-significant .5% of the variance in TPACK implementation, R^2 = .005, F (1, 348) = 1.617, p = .204.

Step 2: Adding TPACK increased the explained variance by 10.7%, ΔR^2 = .107, ΔF (2, 347) = 41.908, p < .001, raising the total R^2 to .107. TPACK was a significant predictor (B = 1.062, 95% CI [0.996, 1.129], β = .258, t = 31.438, p < .001).

Step 3: The inclusion of TCK further increased the explained variance by 50.10%, ΔR^2 = .501, ΔF (3, 346) = 447.994, p < .001, for a total R^2 = .613. TCK was a significant predictor (B = 1.109, 95% CI [1.048, 1.170], β = .285, t = 35.657, p < .001).

Step 4: Adding CK increased R^2 by 17.10%, ΔR^2 = .171, ΔF (4, 345) = 273.855, p < .001, resulting in a total R^2 = .784. CK was a significant predictor (B = 1.075, 95% CI [1.000, 1.150], β = .262, t = 28.1

Step 5: Including PK contributed an additional 10.50% to the explained variance, ΔR^2 = .105, ΔF (5, 344) = 3125.569, p < .001, bringing the total R^2 to .889. PK was a significant predictor (B = 0.975, 95% CI [0.924, 1.025], β = .305, t = 37.694, p < .001).

Step 6: Adding PCK contributed an additional 6.9% to the explained variance, ΔR^2 = .069, ΔF (6, 343) = 576.478, p < .001, raising the total R^2 to .959. PCK was a significant predictor (B = 0.922, 95% CI [.874, .969], β = .277, t = 38.241, p < .001).

Step 7: Finally, incorporating TK resulted in a modest but significant improvement of 2.90%, ΔR^2 = .029, ΔF (7, 342) = 773.742, p < .001, yielding a total R^2 = .987. TK was also a significant predictor of TPACK

implementation (*B* = .859, 95% CI [.798, .920], β = .269, *t* = 27.816, *p* < .001).75, *p* < .001).

Discussion

The findings of this study indicate that participants possessed relatively stronger theoretical awareness of TPACK, followed by basic digital literacy and generally positive attitudes toward technology integration. Although some participants had encountered the TPACK framework through in-service professional development, their technological integration competencies appeared to be developing rather than fully established. This pattern suggests that exposure to conceptual knowledge and technology-related training provides an important foundation; however, awareness alone may not guarantee the meaningful application of technology in instructional practices. The finding is consistent with recent research emphasizing that teachers' technology integration competence requires the coordinated development of technological knowledge, pedagogical understanding, and content-specific application rather than isolated technological skills (Koehler et al., 2014; Schmid et al., 2021). Thus, the observed level of awareness among participants represents a necessary but insufficient condition for sustainable technology-enhanced teaching.

Teacher digital competence emerged as a critical condition shaping effective TPACK implementation. Within the context of Haramaya University, participants' technology integration appeared to be associated with prior professional learning experiences, confidence in using digital tools, and the ability to connect technological resources with instructional purposes. However, the findings also reveal a persistent challenge in translating theoretical understanding into classroom practice. This suggests that professional development initiatives should move beyond introducing digital tools and focus on situated learning experiences where teachers actively design, implement, and reflect on technology-supported lessons. Recent studies have similarly argued that meaningful technology integration

depends not only on individual teacher competence but also on institutional conditions, including access to infrastructure, technical assistance, and continuous professional learning opportunities (Falloon, 2020; Tondeur et al., 2020). Therefore, improving TPACK implementation requires a systemic approach that simultaneously addresses teachers' knowledge, beliefs, and the organizational environment in which technology integration occurs.

The findings further demonstrate that teachers' beliefs and perceptions regarding technology significantly influence implementation practices. Teachers who perceive technology as a pedagogical resource are more likely to explore innovative instructional approaches, whereas those who view technology as an additional workload may demonstrate limited engagement despite having access to digital resources. This finding reinforces the argument that technology integration is not solely a technical process but also a cognitive and pedagogical transformation requiring changes in teachers' beliefs about teaching and learning (Scherer et al., 2021). Consequently, teacher education programs and continuing professional development initiatives should emphasize both technological competence and pedagogically meaningful technology use.

A major contribution of this study is the identification of five prominent barriers limiting TPACK implementation: inadequate technological infrastructure, large class sizes, insufficient professional development opportunities, limited instructional time, and inadequate digital literacy. These barriers illustrate that challenges associated with technology integration extend beyond individual teacher capacity and are embedded within broader educational systems. In contexts such as Ethiopian secondary education, where resource constraints and uneven digital infrastructure remain persistent concerns, teachers may understand the value of technology but experience difficulties applying it consistently in real classroom settings. Recent evidence from developing educational contexts similarly indicates that infrastructure

availability, institutional readiness, and continuous support mechanisms are essential conditions for successful technology integration (Mishra, 2020; Yu & Hu, 2022).

The finding regarding limited practical implementation despite theoretical familiarity highlights an important distinction between knowing about TPACK and enacting TPACK. Although participants demonstrated awareness of technological, pedagogical, and content-related concepts, classroom-level integration remained constrained. This gap suggests that professional development programs should prioritize experiential and discipline-specific learning opportunities rather than primarily theoretical presentations. Effective TPACK development requires teachers to engage in authentic instructional design activities where they learn how specific technologies can enhance subject areas and learning outcomes (Baran et al., 2020; Hsu et al., 2022).

The pattern of TPACK domain implementation provides further insight into the nature of teachers' technology integration competencies. Among the seven TPACK domains, Pedagogical Content Knowledge (PCK) was the most consistently implemented, followed by overall TPACK and Technological Pedagogical Knowledge (TPK).

This finding indicates that teachers continue to demonstrate stronger competence in connecting subject matter with pedagogical approaches developed through conventional teacher preparation. However, the relatively lower implementation of Technological Content Knowledge (TCK) suggests that teachers experience greater difficulty identifying how specific technologies can transform the representation, exploration, and delivery of subject content. This finding is theoretically meaningful because effective technology integration requires more than familiarity with digital tools; it requires teachers to understand how technological affordances interact with disciplinary knowledge and pedagogical strategies (Mishra, 2020; Schmid et al., 2021).

The relatively limited enactment of the integrated TPACK construct further indicates a persistent gap between conceptual understanding and classroom application. Although teachers may possess knowledge of individual domains, the ability to synthesize technology, pedagogy, and content in authentic teaching situations requires sustained opportunities for practice, reflection, and feedback. Recent studies have similarly demonstrated that TPACK develops progressively through contextualized professional experiences rather than through short-term technology training alone (Baran et al., 2020; Falloon, 2020). Therefore, professional development programs should move beyond general ICT literacy and emphasize subject-specific technology integration, collaborative lesson design, classroom experimentation, and reflective practice.

The correlation analysis revealed that TPACK implementation was most strongly associated with PK, followed by TCK, CK, PCK, TK, and overall TPACK knowledge. Interestingly, TPK did not demonstrate a meaningful relationship with implementation. This finding suggests that general understanding of how technology can support pedagogy may not automatically translate into effective classroom practice. Instead, teachers may require deeper knowledge of how particular technologies support specific disciplinary goals. The strong association between TCK and implementation emphasizes the importance of contextualized technological knowledge, where teachers understand not only how to use technology but also why and when a particular technology enhances learning within a specific subject area.

The predictive analysis further revealed that TCK, CK, PK, PCK, TK, and overall TPACK significantly contributed to explaining variations in TPACK implementation, whereas TPK did not emerge as a significant predictor. This finding challenges the assumption that broad knowledge of technology-supported pedagogy alone is sufficient for successful integration. Instead, it highlights the importance of subject-specific technological applications and foundational teaching knowledge in

shaping meaningful classroom practices. Although previous studies have identified integrative domains such as TPK and PCK as important predictors of technology integration, variations across contexts may be explained by differences in teacher preparation, technological infrastructure, institutional support, and educational culture (Tondeur et al., 2020; Yu & Hu, 2022). Therefore, the current findings contribute to the literature by demonstrating that the relative influence of TPACK domains may differ depending on contextual conditions.

Conclusions

The findings of this study demonstrate that teachers possessed a reasonable theoretical understanding of the TPACK framework and generally positive attitudes toward technology integration; however, these strengths were not consistently translated into effective classroom practice. Although PCK and overall TPACK were relatively well developed, the practical integration of technology with subject content and pedagogy remained limited. Moreover, technological content knowledge (TCK), content knowledge (CK), pedagogical knowledge (PK), and pedagogical content knowledge (PCK) emerged as significant contributors to TPACK implementation, whereas technological pedagogical knowledge (TPK) did not significantly predict implementation. These findings suggest that effective technology integration depends not merely on teachers' familiarity with digital tools but on their ability to contextualize technology within subject-specific pedagogical practices. Therefore, developing teachers' integrated competencies requires continuous opportunities to connect theory with authentic instructional experiences.

The study further revealed that TPACK implementation is influenced by both individual and institutional conditions. Persistent barriers, including inadequate technological infrastructure, limited professional development opportunities, large class sizes, insufficient instructional time, and low levels of digital competence, continue to constrain teachers' ability to implement technology-enhanced instruction

effectively. These findings indicate that improving technology integration requires a systemic rather than an individual approach. Sustainable implementation of the TPACK framework depends on coordinated investments in institutional capacity, technology infrastructure, and practice-oriented professional learning. Consequently, strengthening TPACK implementation in Ethiopian secondary education requires collaborative efforts among teacher education institutions, educational leaders, policymakers, and teachers to establish enabling environments that support meaningful and contextually appropriate technology integration.

Recommendations

Based on the findings, teacher education institutions and educational policymakers should redesign continuing professional development (CPD) programs to emphasize integrated TPACK development rather than isolated ICT skill acquisition. Professional learning should provide sustained, collaborative, and classroom-based experiences that enable teachers to design, implement, and evaluate technology-supported lessons within their specific subject areas. Particular attention should be given to strengthening TCK, as this domain demonstrated the strongest contribution to effective TPACK implementation. Furthermore, pre-service, and in-service teacher education curricula should incorporate authentic technology integration activities, lesson design projects, peer collaboration, mentoring, and reflective practice to bridge the gap between theoretical knowledge and classroom application.

Educational authorities should also prioritize institutional conditions that facilitate technology integration. Investments in reliable digital infrastructure, instructional technologies, internet connectivity, and technical support services capacity are essential for creating environments conducive to technology-enhanced teaching. In addition, educational institutions should establish policies that encourage

continuous professional learning, recognize innovative instructional practices, and allocate adequate time for teachers to experiment with technology in authentic classroom settings. These coordinated interventions would strengthen teachers' confidence, improve instructional quality, and promote sustainable implementation of the TPACK framework across diverse educational contexts.

Limitations

Some of the limitations of the study should be considered when interpreting the findings of this study. First, the study relied primarily on self-reported questionnaire data, which may be influenced by social desirability and participants' subjective perceptions rather than actual classroom practices. Second, the study was conducted within a specific institutional and geographical context, which may limit the generalizability of the findings to other educational settings with different technological, organizational, and policy environments. Third, the cross-sectional design captured teachers' competencies and perceptions at a single point in time and therefore cannot establish changes in TPACK implementation over time or infer causal relationships among the investigated constructs. Consequently, the findings should be interpreted within the contextual boundaries of the study.

Future Research

Future studies should employ longitudinal, mixed-methods, and classroom observation designs to examine how teachers' TPACK competencies evolve over time and how they are translated into authentic instructional practice. Researchers should also investigate additional contextual determinants of TPACK implementation, including leadership support, institutional culture, teacher self-efficacy, professional learning communities, digital readiness, and educational policy. Comparative studies across universities, regions, and educational levels would further enhance understanding of contextual

variations in technology integration. Such investigations would contribute to the development of more comprehensive, evidence-based strategies for strengthening teachers' technology integration competencies and promoting sustainable implementation of the TPACK framework in rapidly evolving digital learning environments.

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