Technological, Pedagogical, and Content Knowledge (TPACK) of Secondary Mathematics Teachers: An Exploratory Sequential Mixed Methods Design

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ABSTRACT

This study uses an exploratory sequential mixed methods design to investigate the gap between the literature on technology integration and the actual practices of mathematics teachers in the Philippines. Semi-structured interviews were conducted with seven secondary Filipino mathematics teachers, and the data were subjected to thematic content analysis. Three key themes emerged from the qualitative data: TPACK levels, technological training, and ICT support. Based on these themes, along with insights from the literature and interviews, questionnaires were developed and administered to 60 Filipino secondary mathematics teachers in Central Luzon, Philippines. Confirmatory Factor Analysis (CFA), convergent, and divergent validity tests suggest that the models exhibit a good fit and that the theoretical constructs of Technological Pedagogical Content Knowledge (TPACK) and ICT Support are well-represented by the observed data. The results of regression analysis indicate that organizational support, age, and school-type affiliation significantly influence Filipino mathematics teachers' technological, technological-pedagogical, and technological-content knowledge. In addition, there is a notable difference in the levels of these knowledge domains among different age groups. The findings provide valuable insights into the factors affecting technology integration in mathematics teaching, offering school administrators actionable recommendations to support and enhance teachers' technology-related competencies.

Keywords: TPACK, Filipino secondary mathematics teachers, organizational support, ICT support.

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1. INTRODUCTION

1.1 Background

The now perfunctory integration of technology in mathematics teaching is becoming more intricate once realized that evolving technologies present legitimate concerns to teachers. In the mathematics education realm, technology is the term applied to both analog and digital, new, and old. Nonetheless, the technologies considered herein are the newer digital ones that entail inherent properties that applying in an easily perceptible manner is often, difficult.

Digital technologies, such as computers, handheld devices, and software applications, are increasingly employed in educational settings through tools like online tutorials, courses, discussion forums, virtual classrooms (Inada, 2023), and digital

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communication channels to enhance learning (Brioso, 2017; Komlayut and Srivatanakul, 2017; Sugandini et al., 2022). However, these technologies also present challenges, as both students and faculty may lack the necessary skills for effective use (Komlayut and Srivatanakul, 2017). Some technologies require specific aptitudes to optimize their potential, not to mention affordance and learning their constraints (Bromley, 1998). Considering the current study's concern is on teacher education, the focus, therefore, is to understand technologies' potentialities and limitations influencing mathematics educators on how they conduct classes. Teaching is not straightforward anymore and may entail rethinking teacher education, or teachers may consider retooling through professional development programs.

The discourse involves allusions to the framework of teacher knowledge for the integration of technology coined as technology, pedagogy, and content knowledge (TACK) by Mishra and Koehler (2007). The framework is built on the construct of Lee Shulman (1986), the Mathematical Knowledge of Teaching (MKT). Underscoring one of MKT's two components, the pedagogical content knowledge (PCK) is fortified with technology for more effective teaching (Mishra and Koehler, 2007), with Subject Matter Knowledge (SMK) is the other component of MKT (Shulman, 1986).

On the one hand, tracing the Technological, Pedagogical, Content Knowledge (TPACK) framework as the teacher's PCK as the underpinning of quality and effective teaching (Karaman, 2012; Park and Oliver, 2007; Shulman, 1987). On the other hand, societal progress saw the significant technology revolution in the current times, prompting Clark (2010) to postulate that integrating technology in the curriculum and instruction leads to the desired student achievement of a deep understanding of concepts. Effective technology integration pertains to the process of matching the most effective tool with the most appropriate pedagogy to attain the learning goals of a particular lesson. The concept of integration is in conjunction with the identified goals of Mishra and Koehler (2007) of introducing technology to Shulman's (1986) PCK in addressing the growing prominence of digital technologies in instructional settings, describing the integration of technology into the learning system.

Amidst the technological advancement era, mathematics education needs to still anchor its realm on primordial philosophical foundations. Mathematics education is focused on capacitating learners with real-world problem-solving. Emphases are drawn on the postulations of Yuxin Zheng (1994). Summing it up, mathematics is all about problem-solving: it is best learned by doing, and that mathematical knowledge and skills acquisition occurs within the context of the microscopic and the macro levels (Martin et.al., 2021; Zheng, 1994). Studies aver: on a micro level, the psychology of mathematics teaching originates in the psyche which may flourish through the cognitive science approach reinforced with a constructivist view; and on the macro level, the sociocultural approach that coalesces mathematics teaching and learning with the features of the time, about a social construction where the role of the teacher is the intermediary between the educational system and the objectives of education (Chuang and Xueyen, 2022; Gravemeijer, K., 2021; Zheng, 1994).

On the part of the Philippine government, its national development plan prioritizes elevating the quality of life of Filipinos by establishing high economic growth, aspect of science, technology, engineering, agriculture, and mathematics (STEAM) through its "AMBISYON NATIN 2040" (Philippine Development Plan [PDP], 2017). The country's 2040 goal is seen to be concretized by naming key areas of the crafted plan which includes: 1) enhancing social fabric; 2) reducing inequality; and 3) increasing growth. Among others, the three priority areas put a premium on the promotion of technology, and the stimulation of innovation. The PDP framework posits STEAM as one of the cores

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of realizing the 2040 goals. This compels the rethinking of quality STEAM education for Filipinos.

Specifically, the government thrust likewise necessitates mathematics educators to employ interweaving techniques and methods and embrace crosscutting strategies. There exists a wide gap, a need to conduct a vast array of analyses on variables to study "institutional affordances", to dissect the capacity of educational institutions to provide a conducive learning environment, sufficient and appropriate physical facilities and properties, substantial financial appropriations, and training schemes to support the bedrock and operational processes in delivering STEAM education (Morales et.al., 2019).

1.2 Definition of the Problem

In the landscape of education in the Philippines, there exists a gap between the literature on the incorporation of information technology and the actual practices and experiences of mathematics teachers in delivering quality education within the context of psychological and sociocultural underpinnings.

Relative thereto, this paper looked into mathematics educators in Central Luzon, Philippines as to their predicament, practices, and experiences in navigating the technological era, including expectations of mathematics teachers along well-defined career stages of professional development from the start and current practice; engagement of mathematics teachers in embracing a continuing effort to attain proficiency; and applying measures to improve performance, identifying needs for furtherance.

1.3 Significance and Hypothesis of the Study

One overriding justification for these analyses is to dig deeper into the reasons for the apparent vacillation of many mathematics teachers who have earned degrees in times when technology is no longer comparable with the present advancement of computers and software applications. On this contention comes the main hypothesis of this study, the social and institutional epochs are not enough to make mathematics teachers cognizant of their being insufficiently prepared to use technology in the classroom and that they do not appreciate its value or pertinence to teaching and learning.

1.4 Objectives

The study examines the challenges mathematics teachers face, particularly in integrating technology into teaching. It focuses on social and organizational factors influencing this integration and evaluates the teachers' Technological Pedagogical Content Knowledge (TPACK). The study also assesses the adequacy of teachers' prior training and experiences with technology in education.

1.5 Statement of the problem

Specifically, the study shall seek to:

1. Describe the TPACK of the mathematics teachers;
2. Establish the social and institutional contexts by which mathematics teachers integrate technology into their classroom teaching. Present the technological training and experiences of the mathematics teachers; and,
3. Determine the approach and extent of technological use in their functions

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as mathematics teachers.

2. REVIEW OF RELATED LITERATURE

Technology is continually developing and taking on ever-growing importance in our daily lives. Students of today are becoming increasingly adept at using technology. For various reasons, schools have been attempting to increase the use of technology in the classroom (Gulli, 2021).

In mathematics education, teaching with technology to support conceptual development has been the focus for decades (NCTM, 2014). Utilization of technology can help mathematics teaching and learning. As stated by NCTM (2000), technology influences how mathematics is taught and improves students' learning. The use of technology in teaching mathematics and statistics leads to improved understanding and enhances learning performance and quality (Trisno, 2014; Homa and Oliveira, 2020; Kay and Ruttenberg-Rozen, 2020; Radović et al., 2019; Bukhatwa et al., 2022) and offers several opportunities to build students' conceptual knowledge about mathematics (Roblyer & Doering, 2014).

2.1 On Social and Institutional Impact

The study by Khe Foon Hew and Thomas Brush (2006) presented empirical analyses of gaps and recommendations for the integration of technology into K-12 teaching and learning. Key to their findings is the listing of institutions as sources of opaque and parsimonious support systems rendering technology integration barriers. The other barriers mentioned are insufficient resources, lack of knowledge and skills, attitudes and beliefs of relevant sectors, assessment challenges, and stiff subject culture (Khe F. H. and Brush, 2006). Specifically, their study made a pronouncement, that the lack of specific technology knowledge and skills, technology-supported pedagogical knowledge and skills, and technology-related classroom management knowledge and skills have been identified as major barriers to technology integration.

2.2 On Teachers' Technological Capabilities

Mathematics teachers are unnecessarily burdened by particular connotations from learners on its relevance to real-world situations, a tough subject, among other things that make mathematics unpopular. Colgan, in 2014, pointed out that numerous students consider mathematics as an uninteresting and disengaging subject, and they hate mathematics and try to keep away from it because of mathematics anxiety (Colgan, 2014).

Moreover, teachers' beliefs, anticipated concerns, and benefits about using technologies for teaching and learning mathematics are tied to teachers' lack of confidence and competence, which are another factor in technology integration (Bingimlas, 2009; Mailizar et al., 2020).

2.3 On Teachers' Approaches and Extent of Use of Technology

On the other hand, emphases must also be made on the approaches and extent of the use of technology in teaching. S. Pradeep Gnanam, et.al. (2016) presented an approach for

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integrating ICT in the teaching-learning process. A significant point made by the study is that the potential of new technologies to support innovation towards more student-centered approaches in the learning environment will only be realized if the use of new technologies is prescribed within the context of the whole curriculum. The study concluded, that inappropriate use of technologies in the teaching and learning environment can be minimized through the suggested approach which does not focus primarily on technology but instead directs focus on learner needs, discipline requirements, learning outcomes, and reflection on teaching practices; and Finally, culminated their arguments with the statement, technology implemented as an integral component of teaching and learning strategies formulated to meet learner and discipline needs is most likely to efficiently accomplish the intended learning outcomes (Gnanam, S.P. et. al, 2016).

2.4 On TPACK

The widespread presence of technology in today's society offers various ways to integrate some of that technology into the classroom setting. However, granted that teachers are proficient in utilizing everyday technologies such as cell phones and tablets, implementing these into the classroom in authentic and content-rich ways can be more challenging (Martin et al., 2021).

Önal and Çakır (2015) reaffirms that in current educational practices, effective use of technology in education is only possible when teachers, who are responsible for instructing, supervising, and directing students, are well-equipped and trained in a way that will allow them to use instructional technologies effectively. Access to technology alone does not ensure integration and technology alone does not ensure students' learning (Robinson, 2007; Adedokun-Shittu et al., 2013).

Taking off from the MKT theory of Shulman (1986), Koehler, M.J., et. al. (2014) developed the technological pedagogical content knowledge (TPACK). Shulman (1986) popularized a theory that effective teaching requires a specific type of knowledge, pedagogical content knowledge (or PCK). It represents "the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction" (Shulman, 1986).

Mishra M.J. et al. (2016) dealt with the components in the TPACK framework to explicitly address how the three bodies of knowledge interact, constrain, and afford each other.

Talib et al. (2016) further elaborated that utilizing the TPACK framework can support teachers in their teaching and learning as well as in exploring technology use, including pedagogy and content. Hence, the TPACK framework illustrates how teachers can integrate technology with pedagogy and content knowledge to achieve effective technology-based teaching and learning. Additionally, it develops into a technological foundation that makes teaching and learning enjoyable. (Naziri, Rasul, and Affandi, 2019).

The following defines the framework of the study:

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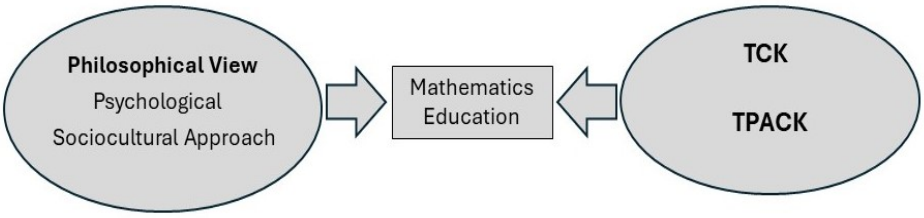

Figure 1. Framework of the Study
Juxtaposing TPACK with Psychological/Sociocultural Approach

3. METHODOLOGY

This study utilizes an exploratory sequential mixed methods design, as outlined by Creswell and Clark (2011). The research begins with qualitative data collection and analysis to identify key themes. These identified themes subsequently inform the development of quantitative instruments, which are used to further investigate the study's research objectives.

3.1 Participants

In the qualitative phase, seven secondary mathematics teachers from three provinces in Central Luzon, Philippines, were purposively selected for semi-structured interviews and assessments of their video presentations and academic documents.

In the quantitative phase, a survey based on the qualitative results was conducted among 60 secondary mathematics teachers from the same provinces. The survey was administered online using Google Forms. Table 1 provides the demographic profile of the survey respondents.

Table 1. Demographic profile of survey sample (*N=60*)

Category	Subcategory	Frequency	Percentage
Gender	Male	23	38.3
	Female	37	61.7
Age	<30	22	36.7
	30-39	20	33.3
	40-49	11	18.3
	≥50	7	11.7
Highest Educational Attainment	Bachelor’s	45	75.0
	Master’s	15	25.0
School Type Affiliation	Public	47	77.9
	Private	13	22.1
Years of Teaching Experience	≤5	32	52.9
	6-10	15	25.0
	11-15	10	16.3
	15+	4	6.7

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3.2 Instruments

This study employed the "TPACK Scale for Secondary Mathematics Teachers (TPACK-SSMT)" questionnaire, which was developed based on the theoretical framework of Mishra and Koehler (2006) and comprised seven theoretical domains. The validated items for the TPACK-SSMT were derived from the qualitative findings of this study, including themes, interviews, and documentary analysis, as well as relevant literature such as Schmid et al. (2020) and Krauss et al. (2008). Additionally, the study adapted the "ICT Support Scale" questionnaire from Day et al. (2012). The items from these two questionnaires were reviewed by a panel of secondary mathematics teachers and educational technology experts for face and content validity.

The TPACK-SSMT consisted of 28 items distributed across the seven domains, while the ICT Support Scale comprised eight items covering two domains: Organizational Support and Peer Support. Both questionnaires utilized a five-point Likert scale (1=strongly disagree, 2=disagree, 3=neutral, 4=agree, 5=strongly agree). The survey also collected demographic data from respondents and information about the training sessions they had attended in the past two years.

3.3 Data Analysis

Thematic content analysis, contextualization, and presentation were carried out to draw an image of the identified contents and subjects of the study. The qualitative data were subjected to the descriptive coding process (Saldana, 2013) undertaken from the interview transcripts and notes, video recordings, instructional/lesson plans, course syllabi, curriculum documents, other instructional materials, and some classroom artifacts which reflected experientially on the topics of this study.

As for the quantitative data, confirmatory factor analysis was run in Jamovi 2.3.21 on each scale. The following fit indices were used: Chi-square/degree of freedom (χ^2/df) ≤ 5 (Hair, Black, and Babin,2019), Tucker Lewis index (TLI) ≥ 0.90 (Bentler and Bonnet, 1980), comparative fit index (CFI) ≥ 0.96, and root-mean-square error of approximation (RMSEA) ≤ 0.06 (Hu & Bentler, 1999).

To check the convergent and discriminant validity of the measurement model, WarpPLS v8 was employed. Cronbach’s alpha (α) and composite reliability (CR) were applied to assess internal consistency, with a threshold value of 0.70 (Hair, Black, and Babin, 2019). Additionally, the following thresholds for convergent validity were set: factor loadings ≥ 0.80 and Average Variance Extracted (AVE) ≥ 0.50. Finally, the Fornell-Larcker criterion was applied to assess the divergent validity of the constructs.

Regression analysis was conducted to establish a relational model of the identified factors (based on the qualitative results) influencing mathematics teachers’ technological, technological-pedagogical, and technological-content knowledge of mathematics teachers.

To support the interpretation of the findings on the joint qual-quan results, the Kruskal-Wallis test, followed by the Dwass-Steel-Critchlow-Fligner (DSCF) pairwise comparisons test was conducted to compare the differences in the levels of technological, technological-pedagogical, and technological-content knowledge of mathematics teachers among different age groups. The Kruskall-Wallis test was chosen because Levene's test showed that the age groups had different variances ($p<0.05$).

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4. RESULTS

4.1 The Qualitative Results

Theme 1: TPACK of the mathematics teachers

The study primarily determined the teacher's level of knowledge of content-specific materials and how the teacher infused technology into the content utilizing the best teaching practices. With this in mind, the teacher participants' evaluation of the three TPACK components, the Technological Content Knowledge (TCK), the Pedagogical Content Knowledge (PCK), and the Technological Pedagogical Knowledge (TPK) were evaluated.

Table 2. TPACK Assessment of the Mathematics Teachers

Teacher	TCK	PCK	TPK
1	S	VS	S
2	VS	S	S
3	VS	VS	VS
4	S	S	S
5	S	S	S
6	VS	VS	VS
7	VS	S	S

TCK is the knowledge of the reciprocity between technology and the content. Subject matter knowledge, especially the grasp of mathematical concepts should be defined clearly, since it may easily be constrained by technologies in their representational and functional abilities (Koehler, M.J., et. al., 2014). With this as the main guiding factor in the developed rubric, Teacher 1, Teacher 4, and Teacher 5 were not given very satisfactory assessments because of their limitations manifested in their Technological Knowledge (TK). Unlike Teacher 2, Teacher 3, Teacher 6, and Teacher 7 who manifested very satisfactory knowledge and mastery of technology in the classroom (TK), they likewise manifested indicators of very satisfactory knowledge of subject content such as concepts, showed evidence of proof and established practices including ways to develop such knowledge (Content Knowledge or CK). Teacher 1 likewise was evaluated very satisfactorily in her CK. Teacher 2, Teacher 3, Teacher 6, and Teacher 7 showed very satisfactory knowledge in linking together technology and content in bringing about learning that is built upon strong subject knowledge and a mastery of more than the subject they teach.

Anchoring on the Pedagogical Content Knowledge (PCK) of Shulman's (1986) notion of an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction, the rubric on PCK was used to evaluate the recordings, interviews and other materials of the teacher participants. The CK assessments presented in the first TPACK component are paired with the Pedagogical Knowledge (PK) of the participants. Indicators found in Teacher 1, Teacher 3, and Teacher 6 showed very satisfactory knowledge and practice of teaching and learning that they use in classroom management, planning, and assessment of their students' performance. Teacher 1, Teacher 3, and Teacher 6 showed evidence and proof of their very satisfactory understanding of how teaching and learning may change when particular technologies are used in particular ways.

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Referring to Technological Pedagogical Knowledge (TPK) as an understanding of technology that can constrain and afford specific pedagogical practices, evaluating presented indicators for this competency resulted in Teacher 3 and Teacher 6 with very satisfactory TPK.

Theme 2: Technological training and experiences of the mathematics teachers, and approaches and extent of technological use in mathematics teaching

In general, the technological training of the teacher participants is confined to the acquisition of basic skills to be familiar with the features of computers and the use of common software applications.

Teacher 1, who earned a bachelor's degree 16 years ago, recalls her IT education in college, which focused mostly on theoretical discussions with minimal exposure to computer laboratories. The same can be said with the technological background of Teacher 2, Teacher 3, Teacher 4, and Teacher 5. Their respective college curriculum likewise mostly dealt with theories, and they were asked to prepare Word documents, simple spreadsheets, and PowerPoint presentations.

The experience of Teacher 6 as an engineering graduate in a university provided him with computer proficiency. His knowledge and skills took off with several computer courses in college including a programming course. The rest of his IT computer skills are mostly, self-acquired. He had to take professional education units before hurdling the licensure exam for teachers soon after.

The participants teaching in public schools participate in periodically conducted professional development projects by the education department, some of which are IT-related. Such training, seminars, and workshops deal with using IT for classroom management, using spreadsheets for instruction and research purposes, and developing instructional materials using open-source applications software.

Teacher 3 and Teacher 7, who consider themselves "tech savvy," received comprehensive computer training hosted or sponsored by the schools employing them. Teacher 7 took IT programs to enhance his skills in advanced data analytics, which enabled him to handle courses at the college level of the same educational institution where he teaches senior high school.

During an encounter with the education program supervisor, the researcher was informed of the education department's programs offering grants for intensive training and scholarships for IT and IT-related graduate programs. None of the seven teacher participants received any of the said grants.

Technological use in the context of this study pertains to the actual utilization of digital devices and applications for purposes of actual mathematics teaching.

It is not surprising to know that Teacher 3 and Teacher 7 are the only two among the teacher participants who go beyond the use of computers as instruments to present instructional materials developed using Microsoft Word, MS Excel, and PowerPoint.

Teacher 1 is candid enough to admit she seldom uses computers in her classroom teaching. The few times that she does, she presents PowerPoint presentations to introduce new lessons, if only to spare herself from repeatedly writing and drawing on the board the same texts and figures, class after class.

In the classes of Teacher 3 and Teacher 7, Kahoot and Duolingo are staples that are used at least once a week. Games and similar activities are designed to start their classes as a form of motivational activities, or review of past lessons. Their lesson plans show 5 to 10 minutes of allotment for these activities. These two teacher participants allow their students to use applications software such as Geogebra, Photomath, Matlab,

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and mathematics features of Microsoft Excel during exercises and drills, but these may not be accessed during tests. Teacher 5 used to do the same as Teacher 3 and Teacher 7 when she was still employed at the private university in Cabanatuan City, stating that in her current workstation, not all students have access to digital devices, not all the classrooms she is assigned to have the necessary gadgets.

Theme 3: How teachers respond to social and organizational expectations in the use of technology in mathematics teaching

First, it needs to be said that all participants showed intrinsic motivation towards teaching as an occupation. Factors presented range from being motivated by the teaching profession and mathematics, beginning with factors relating to students and student progress, to being remembered by them long after students graduate from high school. In the case of Teacher 1, Teacher 5, and Teacher 7, their affinity to mathematics early in their education led them to develop similar attitudes towards mathematics teaching. Teacher 1, Teacher 3, and Teacher 7 expressed satisfaction when seeing students' excitement as a result of learning and felt sufficient when seeing students progressing from one lesson to another.

While the study is focused on the interplay of technology with teachers' delivery of education, the issue of the mathematics curriculum design prescribed by the governing national agency has repeatedly surfaced in the interviews. The spiral progression approach to mathematics is a legitimate concern for all the seven teacher participants. Teacher 1 and Teacher 6 put it more clearly, the desired outcomes may be achieved through cooperative teaching considering students' propensity to forget learnings from their previous grade levels. The participants see such as a smorgasbord, an array of math topics for students repeatedly taken each year, allotting limited time to cover fewer topics per year. To top it all, apprehension on this is more pronounced for Teacher 1, Teacher 3, Teacher 4, and Teacher 6, who expressed moments of confoundment with their articulation on learning competencies for their respective students; one of the reasons commonly mentioned is the availability of instructional materials. These unearthed issues on the spiral curriculum design validate the findings of De Ramos-Samala (2017), who deduced that the design extracts proficiency on the subject matter of teachers and requires the utilization of as many instructional materials that fit the interest of the students.

The perceived requisite for cooperative teaching about the implementation of the spiral progression approach directs the discourse to the next institutional challenge the teacher participants constantly have to deal with, particularly those detailed in public schools. Said teachers handle classes with more than 50 students, with Teacher 1 having to attend to the needs of 78 students at some point. According to Teacher 6, while it is encouraged for teachers to engage in cooperative teaching, their school, being a public school, has to accept all who are qualified to enroll because of the free education law in the country and the policy of the education department of leaving no one behind in the access of education. It becomes nearly impossible to devise the mechanism for cooperative teaching and learning, considering that students from high schools (in the case of Teacher 1, Teacher 2, Teacher 3, Teacher 6, and Teacher 7), students are to choose to attend either the morning or afternoon classes. The school principal of the national high school in Tarlac province confirms this scheme. The scheme is adopted to accommodate a large number of enrollees given the limited number of classrooms and teachers alike. Teacher 3 and Teacher 7, who are teaching in private schools find themselves in a better situation because they only have to deal with 35 to 45 students in their classes, and their students enjoy free time interspersed with their classes in the 5 school days of the week.

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The same principal of the school in Tarlac, alongside the education program supervisor, affirms statements of the teacher participants regarding the issue of providing IT hardware for teachers' use. While there was a program in 2021 by the education department to provide laptop computers to teachers, not all were provided with one, due to limited resources. Teacher 1 and Teacher 6, who received one each are grateful, nonetheless wished for devices with better quality and specifications. Teacher 5 uses a laptop which he acquired when still studying for her education degree. Teacher 2, Teacher 3, and Teacher 7 use their personal laptop computers, while Teacher 4 has to borrow devices from a sibling and, often, from co-workers. The same predicament is experienced by the teachers about technology provisions in the classrooms. While it has become a common sight for schools, both public and private, to have smart televisions for audiovisual presentation purposes, Teacher 2 and Teacher 5 are not all the time assigned to classrooms with such amenities. As far as internet connectivity is concerned, only Teacher 7 experiences mathematics teaching with school/institution-provided network connectivity.

The support of local governments in the provinces of Tarlac and Nueva Ecija was put into discussion. Teacher participants are aware of the efforts of local education boards to advocate for IT integration in schools. Nonetheless, the teachers quipped, and with the high demand and with meagre resources distributed among constituents, the sustainability of said projects is put into question.

The parents/teachers' associations in schools have long been institutionalized. Teacher 3 in particular, appreciates the active involvement of the parents' group in their children's school affairs. Teacher 3 appreciates their support, together with their school administration to put up a math laboratory. Teacher 7 experiences the same facility, their school is known and promoted as an IT education hub in the country. However, the other teacher participants, who are assigned to public schools, do not experience this. While public schools likewise encourage parents' involvement in school activities, an endowment for the acquisition of additional computers for example, or an initiative to finance internet connectivity in school may be easily shut down when at least one parent dissents. This was an experience of Teacher 7, being the adviser of a Special Science Class in their school who wished to provide students with classroom sessions with lessons involving real-time examples available only through the Internet.

Understandably, the policy of the education department to minimize the giving of academic homework frustrates the teacher participants. Parents, according to the teacher participants based in public schools, either support the directive or are nonchalant about the mandate, which is a source of teachers' dismay. When supplemental instructional modules are provided to students, the intention is to augment classroom discussions and forms of remediation, purposes and intentions are defeated partly due to attitudes and capabilities of students and parents, the teacher participants surmise. When asked to access educational materials from the internet, students convey to the teacher participants their inability to comply for varying reasons including non-access to the digital devices and internet connection, despite their presence and up-to-date trends in the social media platforms.

The teacher participants recognized the pros and cons of the issues brought out in the discussion. The extrinsic rewards that come with the occupation do not come unappreciated for the teacher participants. Teacher 1, Teacher 2, Teacher 3, Teacher 4, and Teacher 6, who were in the public education system during the pandemic, are grateful the tribulations during the lockdowns were not as grave as those experienced by most. While the intrinsic motivators of the teachers are commendable, some of the issues enumerated come as a letdown to the zeal and fervor of the teacher participants. Fortunately, nuances

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and their responses contain enough manifestations to categorically say they remain driven to dispense their duties the best they can, and consistently elevate their teaching practice using the technology available to them.

4.2 The Quantitative Results

The total scores of each nine (9) measurement models had skewness ranging from -1.83 to -0.26 within the range of ±2 and kurtosis ranging from -0.21 to -0.11 within the range of ±7, indicating a relatively normal distribution (Hair et al., 2010; Bryne, 2010).

Table 3 presents the fit indices of the eight measurement models as a result of the Confirmatory Factor Analysis. All demonstrate acceptable levels of measurement validity.

Table 4 displays the inter-correlations, factor loadings, AVE, CR, Cronbachs' alpha, mean, and standard deviation (SD) of the subscales. The results indicate good levels of convergent validity, discriminant validity, composite reliability, and internal consistency. In addition, the subscales were significantly positively related to each other, with correlation coefficients ranging from 0.40 (p<.001) to 0.81 (p<.001). Furthermore, the participants had high levels of Pedagogical *(M=4.45, SD=0.61)*, Content *(M=4.21, SD=0.54)*, Pedagogical Content *(M=4.30, SD=0.45)*, and Technological-Pedagogical-Content Knowledge *(M=4.28, SD=0.66)*. Comparatively, they had a lower Technological *(M=4.10, SD=0.68)*, Technological-Pedagogical *(M=3.97, SD=0.69)*, and Technological Content Knowledge *(M=3.95, SD=0.67)*.

Table 3. Fit indices of the measurements model based on Confirmatory Factor Analysis

Model	χ^2	df	p	χ^2/df	CFI	TLI	RMSEA
TPACK-SMST							
1. Pedagogical Knowledge	1.75	2	0.431	0.88	0.97	0.90	0.00
2. Content Knowledge	1.70	2	0.428	0.85	1.00	1.00	0.00
3. Technological Knowledge	2.24	2	0.327	1.12	1.00	1.00	0.04
4. Technological Pedagogical Knowledge	1.84	2	0.401	0.92	1.00	1.00	0.01
5. Technological Content Knowledge	2.55	2	0.280	1.28	1.00	0.99	0.07
6. Pedagogical Content Knowledge	2.66	2	0.265	1.33	0.99	0.96	0.07
7. Technological Pedagogical and Content Knowledge	2.68	2	0.251	1.34	0.99	0.97	0.07
ICT Support Scale							
1. Organizational Support	1.77	2	0.413	0.89	1.00	1.00	0.00
2. Peer Support	1.79	2	0.409	0.90	1.00	1.00	0.00

Table 4. Convergent and divergent validity test; mean and SD of the constructs (*N=60*)

Statistic	1	2	3	4	5	6	7	8	9
1. Pedagogical Knowledge	(0.87)								
2. Content Knowledge	0.76*	(0.84)							
3. Technological Knowledge	0.75*	0.61*	(0.87)						
4. Technological Pedagogical Knowledge	0.72*	0.61*	0.81*	(0.92)					
5. Technological Content Knowledge	0.75*	0.68*	0.85*	0.87*	(0.87)				

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6. Pedagogical Content Knowledge	0.81*	0.77*	0.67*	0.66*	0.77*	(0.74)			
7. Technological Pedagogical and Content Knowledge	0.79*	0.66*	0.79*	0.82*	0.81*	0.70*	(0.92)		
8. Resources	0.53*	0.54*	0.77*	0.72*	0.78*	0.61*	0.66*	(0.91)	
9. Personal assistance	0.46*	0.44*	0.61*	0.66*	0.62*	0.47*	0.61*	0.40*	(0.93)
Factor loadings *(min)*	0.84	0.80	0.81	0.90	0.70	0.71	0.86	0.90	0.87
Factor loadings *(max)*	0.91	0.86	0.91	0.92	0.94	0.84	0.97	0.93	0.96
AVE	0.76	0.71	0.76	0.85	0.76	0.55	0.85	0.83	0.86
CR	0.93	0.91	0.93	0.95	0.92	0.83	0.96	0.95	0.96
Cronbach's α	0.89	0.87	0.89	0.94	0.89	0.71	0.94	0.93	0.94
Mean	4.45	4.21	4.10	3.97	3.95	4.30	4.28	3.60	3.68
SD	0.61	0.54	0.68	0.69	0.67	0.45	0.66	0.82	0.92

Square roots of AVE shown on diagonal
*$p<0.001$

4.3 The Joint Qual-QUAN Results

4.3.1 Age and Technological Knowledge

One recurring theme in the literature, supported by interviews conducted in this study, is that a teacher's age is a crucial factor in determining their technological knowledge. Some studies examining teachers' technological knowledge in the context of age variables have found that age significantly influences technological knowledge (Farida Nur Kumala, Anik Ghufron and Pratiwi Pujiastuti, 2022). However, contrasting studies, such as one by Kerzic et al. (2021), argue that age is not a determinant of ICT skill, especially in using ICT in teaching. This discrepancy may arise because younger individuals are often skilled in using technology for communication and leisure, but they may need to apply it more effectively in educational settings. These conflicting findings regarding the impact of age on technological knowledge underscore the need for further research, particularly in the context of mathematics teaching.

The qualitative findings of this study suggest that older individuals may have had limited access to technology during their college years, resulting in a lower baseline level of technological knowledge. Newhouse (2002) highlights the importance of initial training for teachers to develop the necessary skills, knowledge, and attitudes for effectively using computers to support students. For instance, Teacher 1 reflected, "*My IT education in college, 16 years ago, was mostly theoretical with very little hands-on experience in using computers.*" Similarly, Teachers 2 and 3 mentioned, "*During college, practical skills like using computer labs were quite limited.*"

In contrast, younger individuals often benefit from greater access to educational resources, training, and informal learning opportunities, which enhance their technological skills (van Deursen and van Dijk, 2014). The quantitative results of this study indicate that the number of hours spent in ICT-related professional development varies across different age groups. Specifically, individuals under 30 and those aged 30-39 show a higher concentration of participants engaging in more hours of training over the past two years, compared to those aged 40-49 and 50+ who participated in fewer extensive training hours (Figure 2).

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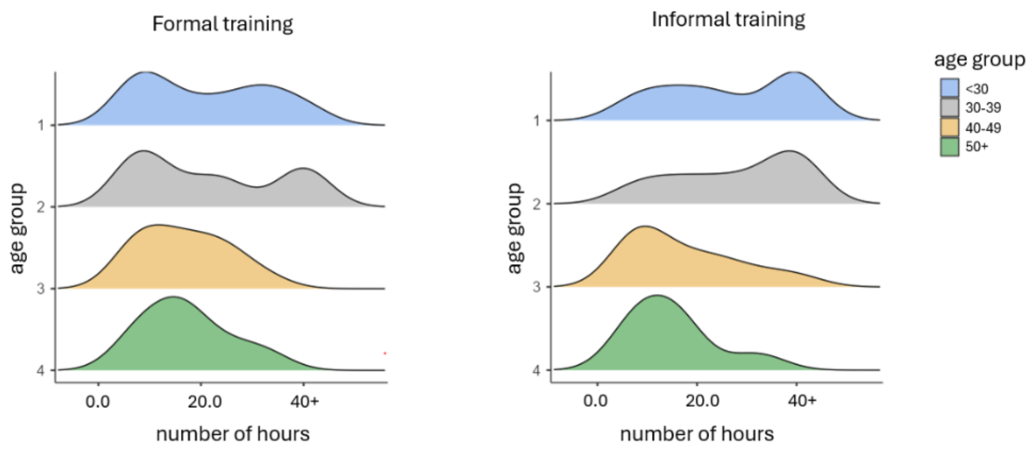

Figure 1. Number of hours spent in ICT professional development

The results of the interviews also implied that the lack of access to resources is another complex factor that impedes teachers from integrating ICT into mathematics education. In addition, the lack of access to ICT resources is not solely attributed to the unavailability of hardware and software within the school. It may also stem from various factors, such as inadequate organization of resources and insufficient support for teachers (Becta, 2004).

4.3.2 ICT Support

Recent studies suggested that ICT support provided to teachers, as well as other stakeholders involved in the process of management and training of the teachers, is an essential factor that plays a significant role in the positive changing of the intention to use technology for educational purposes (Ursavas et al., 2015; Bingimlas, 2009). Moreover, there is a significant relationship between the support provided by management and colleagues and the proficiency of technology use (Perth, 2016; Deli, 2019). In addition, the qualitative data also suggest that the support received by the teacher depends on the type of organization they belong to, whether they belong to public or private institutions.
"I have to manage the needs of up to 78 students at a time, …implementing technology in teaching is quite challenging." (Teacher 1)
"Our public school must accept all qualified students due to the free education law" (Teacher 6)
"I am grateful for the laptop provided by the Department of Education in 2021, but it would be more helpful if the device had better specifications." (Teacher 1)
"Without a personal laptop, I often have to borrow devices from my sibling or co-workers, which makes it challenging to keep up with my teaching responsibilities." (Teacher 4)

Hence, this study wants to evaluate the combined effects of the variables, age, ICT support, and affiliation type on the technological, technological-pedagogical, and technological-content knowledge of mathematics teachers. In this context, the hypotheses of the research were created as follows:

H1: Age, ICT support and school-type affiliation significantly influence mathematics teachers' technological, technological content, and technological pedagogical knowledge.

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H2: The technological, technological pedagogical, and technological content knowledge of mathematics teachers is significantly different across different age groups.

4.3.3 Regression Analysis

The regression model for technological knowledge was significant, $F(6,53) = 20.2, p < .001, R^2 = .70$, indicating that the predictors could explain 70% of the variance in technological knowledge. Organizational support was a significant positive predictor ($\beta = 0.47, p < .001$), while peer support and school and school-type affiliation were not significant. Age was also a significant predictor: compared to the reference group (<30), teachers aged 40-49 ($\beta = -1.92, p = .01$) and those aged ≥50 ($\beta = -2.98, p < .001$) had significantly lower technological knowledge scores.

Table 5. Regression analysis on technological, technological pedagogical, and technological content knowledge of mathematics teachers as a function of organizational support, peer support, and school affiliation

	Technological				Technological Pedagogical				Technological Content			
Predictor	Estimate	SE	t	p	Estimate	SE	t	p	Estimate	SE	t	p
Intercept	11.14	1.52	7.31	<.001	12.63	1.57	8.07	<.001	11.64	1.36	8.59	<.001
Organizational support	0.47	0.11	4.17	<.001	0.26	0.12	2.20	0.03	0.42	0.10	4.20	<.001
Peer Support	-0.02	0.10	-0.24	0.81	0.18	0.10	1.85	0.07	0.00	0.08	-0.03	0.97
School Affiliation												
Private	Reference				Reference							
Public	-0.33	0.63	-0.52	0.60	-1.35	0.65	-2.08	0.04	-1.26	0.56	-2.24	0.03
Age Group [a]				<.01				<.001				<.001
<30	Reference				Reference				Reference			
"30-39"	-0.49	0.52	-0.94	0.35	-0.31	0.53	-0.58	0.57	-0.51	0.46	-1.10	0.28
"40-49"	-1.92	0.69	-2.79	0.01	-1.17	0.71	-1.65	0.11	-1.48	0.61	-2.41	0.02
≥50	-2.98	0.80	-3.75	<.001	-3.43	0.82	-4.19	<.001	-3.47	0.71	-4.90	<.001
F(6,53)		20.2				19.9				26.8		
R^2		0.70				0.69				0.75		
Adj. R^2		0.66				0.66				0.72		
p		<.001				<.001				<.001		

[a] result of Omnibus ANOVA Test

The regression model for technological-pedagogical was also significant, $F(6,53) = 19.9, p < .001, R^2 = .69$. Organizational support was also a significant predictor of technological pedagogical knowledge ($\beta = 0.26, p = 0.03$). Whereas peer support was still not significant. School type affiliation and age had a significant contribution in determining technological pedagogical knowledge. Teachers aged ≥50 had significantly lower technological pedagogical knowledge ($\beta = -3.43, p < .001$) compared to the reference group (<30).

Lastly, the regression model for technological content knowledge was also significant, $F(6,53) = 26.8, p < .001, R^2 = .75$. There was a significant effect of organizational support ($\beta = 0.42, p < .001$) , school type affiliation ($\beta = -1.26, p < .001$) , and age on the technological content knowledge of the mathematics teachers. However, peer support was still not significant. Moreover, teachers aged ≥50 ($\beta = -3.47, p < .001$) and 40-49 ($\beta = -1.48, p = 0.02$) had significantly lower technological content knowledge than the reference group (<30).

4.3.4 Age Groups Differences on Technological Knowledge

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Table 6. Kruskal-Wallis Test on Technological, Technological Pedagogical, and Technological Content Knowledge for different age groups

Age Group	Measures					
	Technological		Technological Pedagogical		Technological Content	
	M	SD	M	SD	M	SD
<30	18.2	1.45	18.7	1.55	17.5	1.79
30-39	16.8	1.77	17.7	1.78	16.4	1.23
40-49	14.3	1.35	15.3	1.10	14.0	1.26
≥50	12.9	4.10	13.3	4.36	11.7	3.73
χ^2	34.0		31.4		34.5	
p	<.001		<.001		<.001	
DSCF* pairwise comparison	*a, b, c, d*		*a, b, c, d*		*a, b, c, d*	

a) post hoc comparisons found a significant difference between the age groups "<30" and "40-49"
b) post hoc comparisons found a significant difference between the age groups "<30" and "≥50"
c) post hoc comparisons found a significant difference between the age groups "30-39" and "40-49"
d) post hoc comparisons found a significant difference between the age groups "30-39" and "≥50"
**Dwass-Steel-Critchlow-Fligner pairwise comparisons*

The results indicated significant differences in all three types of knowledge across the age groups: technological knowledge, $\chi^2(3, N = 60) = 34.0, p < .001$; technological pedagogical, $\chi^2(3, N = 60) = 31.4, p < .0019$; and technological content knowledge, $\chi^2(3, N = 60) = 34.5, p < .001$ (Table 7). Specifically, post hoc pairwise comparisons using the DSCF procedure revealed significant differences between the age groups "<30" and "40-49", "<30" and "≥50", "30-39" and "40-49", and "30-39" and "≥50" for all three types of knowledge (Table 7). These findings suggest that younger mathematics teachers tend to have higher knowledge associated with technology use.

5. DISCUSSION

The study reaffirms the pivotal role of organizational support in bolstering teachers' technological, technological pedagogical, and technological content knowledge. These findings align with prior research, which has consistently shown that adequate resources (Africa and Hub,2020), continuous professional development (Albion et al., 2015; Uslu and Bumen, 2012; Mwangi and Khatete, 2017), and robust organizational support (Nyamogosa and Murimi, 2024; Gürfidan and Koç, 2016) are critical for teachers to adopt and integrate technological tools into their pedagogical practices successfully.

Contrary to expectations, peer support did not significantly predict the three domains of TPACK in this study. Although existing literature underscores the importance of collegial interactions and collaborative learning in fostering professional growth among educators (Owen, 2014) and TPACK in general (Dong et al., 2019), the findings of this study specifically suggest that peer support may be insufficient to substantially impact the three technological domains of TPACK. This divergence suggests that the effectiveness of peer interactions may be contingent upon the expertise and knowledge base of faculty members, which are necessary for meaningful support. Our quantitative results support this proposition, showing that faculty members exhibited lower levels of technological, technological-pedagogical, and technological-content knowledge.

The results of this study also indicate that school affiliation significantly influences technological pedagogical and technological content knowledge. Specifically,

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teachers in public schools exhibited lower TPACK levels compared to their counterparts in private schools. This disparity may be attributable to variations in resource allocation, institutional priorities, and the degree of autonomy teachers have in integrating technology. Public schools often encounter bureaucratic constraints and limited resources, which can impede the effective implementation of technology-enhanced teaching.

The study also identified significant differences in the levels of technological, technological-pedagogical, and technological-content knowledge among the different age groups. Older teachers demonstrated significantly lower levels of technological, technological-pedagogical, and technological-content knowledge, potentially reflecting challenges in adapting to the rapid evolution of educational technologies. The results highlight a lack of baseline ICT knowledge and ICT-related training among older teachers, compared to younger teachers who are more willing to spend time on both formal and informal ICT training. These findings suggest a need for targeted professional development initiatives, focusing on enhancing technological proficiency among older educators to ensure they can effectively integrate new tools and methodologies into their teaching practices. Such initiatives could help bridge the knowledge gap and support a more uniform adoption of educational technologies across all age groups.

6. LIMITATION

A primary limitation of this research is the reliance on purposive sampling, which may lead to selection bias and thus restrict the generalizability of the findings. The quantitative phase involved 60 respondents, a relatively modest sample size. Although confirmatory factor analysis and regression analysis were employed, the small sample size could constrain the statistical power and generalizability of the findings. Furthermore, the questionnaires were designed specifically within the context of mathematics teaching. As a result, the insights and conclusions drawn may not be fully applicable to other educational contexts or subjects. Future research should consider employing a random sampling method and a larger sample size to enhance the validity and generalizability of the results.

7. CONCLUSION AND RECOMMENDATIONS

This study used an exploratory sequential approach to establish conceptual and measurement models of TPACK in the context of mathematics teaching. The qualitative phase of the study explores the psychological and sociocultural contexts that shape teachers' technological backgrounds and practices, providing insights into their TPACK. Evaluating teachers is complex due to the dynamic, contextual, and individual nature of their instructional knowledge and skills. The research emphasizes understanding teachers' challenges and aspirations, noting that their TPACK development must be validated qualitatively within their unique contexts. It highlights the importance of both intrinsic and extrinsic motivations in enhancing TPACK.

The combined qualitative and quantitative analysis reaffirms the positive role of organizational support in enhancing technology-related competencies among mathematics teachers. The study reveals a disparity in technological proficiency between public and private mathematics teachers. Furthermore, significant differences were observed in levels of technological, technological-pedagogical, and technological-content knowledge across different age groups.

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The significant positive influence of organizational support on all three TPACK domains underscores the necessity of a supportive institutional framework to facilitate effective technology integration in mathematics teaching and learning. Specifically, this study suggests that teachers, like students, benefit from differentiated instruction and tailored professional development programs. Recommendations include investing in content-specific professional development, fostering collaboration among teachers, providing constructive feedback, and supporting professional learning communities. These strategies aim to help teachers integrate technology effectively into math education, adapt to evolving educational trends, and continuously develop their teaching skills.

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