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ORIGINAL

TPACK knowledge in secondary school teachers: basis for effective teaching with mobile technologies in digital environments

Conocimiento TPACK en docentes de secundaria: base para una enseñanza efectiva con tecnologías móviles en entornos digitales

Dilenia A. Marte Marte[1]

[1]Universidad de Sevilla, Facultad de Educación. Sevilla, España.

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Corresponding Author: Dilenia A. Marte Marte

ABSTRACT

The digital transformation of educational environments has highlighted the need for teachers to master skills that integrate technology, pedagogy, and subject matter. In this context, mobile learning emerged as an effective strategy for expanding educational coverage, fostering independent learning, and improving academic performance. Its pedagogical integration also lays the groundwork for future collaborations with immersive virtual environments and emerging technologies such as artificial intelligence and augmented reality. This study analyzed the level of TPACK knowledge among secondary school teachers in Regional 08 of the Ministry of Education of the Dominican Republic, considering the educational use of mobile devices. A mixed-method approach was adopted, administering questionnaires to 354 teachers and interviewing 26 school principals. The results revealed that teachers possessed a moderately high level of TPACK knowledge, influenced by factors such as age, gender, professional experience, ICT training, and institutional support. It was concluded that strengthening ongoing training and technical support is key to effective teaching mediated by mobile technologies, with projections toward more advanced educational ecosystems such as the metaverse.

Keywords: Pedagogical Content Knowledge; Mobile Learning; Teacher Competencies; Educational Environment.

RESUMEN

La transformación digital de los entornos educativos ha puesto de manifiesto la necesidad de que los docentes dominen competencias que integren tecnología, pedagogía y contenido disciplinar. En este contexto, el aprendizaje móvil (Mobile Learning) emergió como una estrategia efectiva para ampliar la cobertura educativa, fomentar el aprendizaje autónomo y mejorar el rendimiento académico. Su integración pedagógica, además, sienta las bases para futuras articulaciones con entornos virtuales inmersivos y tecnologías emergentes como la inteligencia artificial o la realidad aumentada. Este estudio analizó el nivel de conocimiento TPACK en docentes de secundaria de la Regional 08 del Ministerio de Educación de la República Dominicana, considerando el uso educativo de dispositivos móviles. Se adoptó un enfoque mixto, aplicando cuestionarios a 354 docentes y entrevistas a 26 directores escolares. Los resultados revelaron que el profesorado poseía un nivel moderadamente alto de conocimiento TPACK, influido por factores como la edad, el sexo, la experiencia profesional, la capacitación en TIC y el apoyo institucional. Se concluyó que fortalecer la formación continua y el acompañamiento técnico resulta clave para una enseñanza efectiva mediada por tecnologías móviles, con proyecciones hacia ecosistemas educativos más avanzados como el metaverso.

Palabras clave: Conocimiento Pedagógico del Contenido; Aprendizaje Móvil; Competencias Docentes; Entorno Educativo.

INTRODUCTION

Mobile learning is an effective educational strategy in the digital age, offering flexibility, ubiquity, and continuity in the teaching-learning process. Its incorporation into teaching requires specific teaching skills, such as those defined by the TPACK model, which articulates technological, pedagogical, and disciplinary knowledge.

In this context, mobile devices have significantly transformed educational environments by promoting continuous access to knowledge and fostering more autonomous, interactive, and equitable practices.[1] This highlights the need for skills to effectively integrate these technologies into teaching practices,[2,3] making it relevant to study teachers' TPACK knowledge about using such devices.

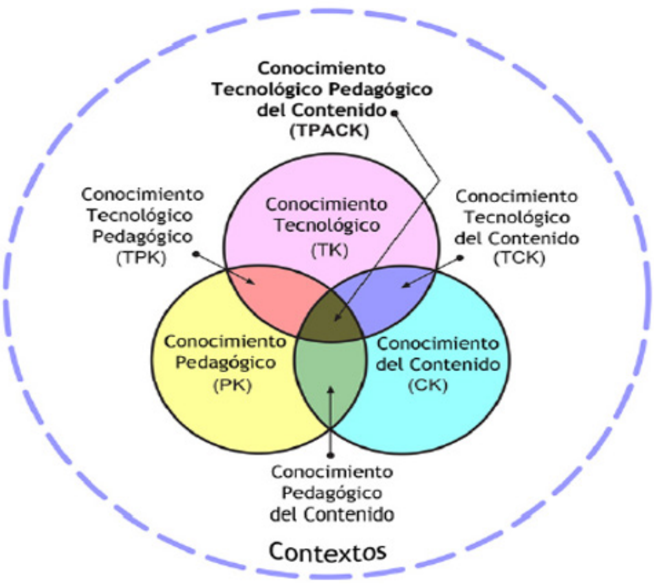
In the past, teacher competence was measured based on content knowledge and pedagogical strategies. However, Schulman argued that these two dimensions are not sufficient to describe effective teaching and, therefore, introduced the concept of pedagogical content knowledge (PCK), which combines content knowledge (CK) and pedagogical knowledge (PK). Although Shulman's original proposal remains relevant, adding innovative technologies to the concept has enriched the debate on teacher competence,[4] even in rural secondary schools.[5]

Mishra et al.[6], based on Shulman[7], proposed a model that broadens teacher knowledge by integrating it into the technological, pedagogical, and disciplinary domains. They propose a model that broadens teacher knowledge, incorporating it into the taught subject's technological, pedagogical, and disciplinary domains. Teachers' technological, pedagogical, and content knowledge (TPACK) enables technology integration for educational purposes.[4,8] The TPACK model is an essential framework for effectively integrating technology in the classroom.[9]

The TPACK model establishes the knowledge that must be possessed to integrate ICT into teaching successfully. This approach measures seven knowledge variables: technological, disciplinary, pedagogical, pedagogical disciplinary, technological disciplinary, technological pedagogical, and technological pedagogical content.[10,11,12,13]

These components are briefly explained below:

- Technological knowledge (TK): mastery of digital tools and technological devices.
- Pedagogical knowledge (PK): mastery of teaching methods and approaches.
- Content knowledge (CK): mastery of subject-specific content.
- Pedagogical content knowledge (PCK): ability to teach content effectively.
- Technological content knowledge (TCK): understanding of how technology can transform disciplinary content.
- Technological pedagogical knowledge (TPK): use of technology to improve pedagogical strategies.
- Technological pedagogical content knowledge (TPACK): holistic integration of the three types of knowledge in real teaching contexts.



Source: http://www.tpack.or|g.

Figure 1. TPACK model

Figure 1 illustrates the TPACK model. This approach also values teachers' experiences, training, and skills.[14] Effective integration of technology is not just about mastering digital tools but about combining content, pedagogy, and technology in an appropriate way. Professional development initiatives differentiated according to teaching experience are proposed in order to improve TPACK competence and, consequently, the quality of science teaching.[15] Although teachers have professional knowledge, they may not have enough experience already to have well-established TPACK frameworks and structures.[16]

The TPACK model has evolved to include context in teaching.[17] This makes it a key model for optimizing technology integration in education.[18,19] In a study conducted by Kosiol and Ufer,[20] they found that its measurement can be improved through contextualized and triangulated assessments.

The pandemic accelerated the adoption of ICT and highlighted the importance of theoretical frameworks such as TPACK and incorporating Artificial Intelligence for faster and more creative methodologies.[21] Several studies show that TPACK-based courses significantly improve teaching skills, so further research on this type of training is recommended.[9] In this context of educational transformation, there is also a recognized need to explore how the TPACK model can be articulated with new digital ecosystems, including immersive environments, advanced mobile technologies, augmented reality platforms, and educational metaverses. This conceptual expansion allows TPACK to be viewed not only as a framework applicable to the present but also as a basis for preparing teachers for the technological challenges posed by future education.

The TPACK model is adaptable to diverse educational settings, making it relevant nationally and internationally,[17] especially when combined with observation and performance analysis methods.[22]

Research on the TPACK model has generated numerous analyses and systematic reviews that, in addition to highlighting the need to consider context, reveal persistent theoretical and methodological problems. Although the TPACK framework is based on Shulman's PCK model and has been expanded to include the technological dimension, reviews show that conceptual clarity and consistent operationalization of its domains have not yet been achieved.[23] This allows for the analysis of various factors that influence teachers' TPACK.

Various studies highlight factors that can influence the development of TPACK knowledge, including infrastructure, institutional support, and training provided.[5,24,25]

A lack of coordination between technology, pedagogy, and content is common in low-resource schools. Laboratory and specific programs are suggested to close the digital divide.[26]

Given its dynamic nature, TPACK requires continuous training that considers teaching experience and contexts.[27] Gómez-Trigueros et al.[28] found gender differences: women perceive lower digital competence than men.

Shiri et al.[29] analyzed how digital literacy, digital skills, and academic level influence TPACK. They conclude that higher educational levels imply greater TPACK competence and recommend specialized training.

During the pandemic, biology teachers demonstrated pedagogical and content strengths but technological weaknesses. Strengthening training in educational technology is recommended.[30]

Drajati et al.[31] showed that TPACK-based programs improve teachers' confidence and beliefs about technology. They highlight the importance of integrating theory and practice and fostering teacher autonomy.

Wu et al.[32] recommend contextualized training programs with performance-based assessments that articulate technology, content, and pedagogy[15] and insist that these policies must be aligned with the challenges of the 21st century.

Maipita et al.[33] found that institutional support and TPACK are key to improving teacher performance by facilitating technology integration.

As shown, the TPACK model has been interpreted from different perspectives, reflecting the complexity of its implementation in real educational contexts. This requires a holistic view that considers its fundamental technological, pedagogical, and disciplinary dimensions and the contextual factors that influence its effective development.

Mobile learning, for its part, has proven to be an effective pedagogical strategy for expanding educational coverage, facilitating active student participation, and improving academic performance.[34,35] However, its pedagogical integration requires teachers to have articulated knowledge to incorporate these technologies into the classroom adequately. In this sense, the TPACK model is an ideal conceptual framework for assessing such knowledge about the use of mobile devices.

The interest in studying TPACK knowledge in this context stems from the multiple benefits that mobile devices offer in teaching-learning, such as portability, accessibility, and ability to personalize the educational experience and foster collaboration.[36,37,38]

In addition, the rise of digital environments such as mobile platforms, immersive spaces, simulators, and intelligent systems demands a teaching profile capable of adapting to these emerging ecosystems. From this perspective, mobile learning should be understood as a consolidated trend and a precursor to integrating more advanced technologies, such as augmented reality, artificial intelligence, or metaverse environments. Assessing teachers' level of TPACK knowledge allows us to identify the extent to which they are prepared to face this expanding technological landscape.

Therefore, this research aims to analyze the level of TPACK knowledge of secondary school teachers in the context of the pedagogical use of mobile devices.

METHOD

This study was developed using a mixed methodological approach, integrating quantitative and qualitative techniques to gain a broader understanding of the phenomenon under investigation. Combining both approaches allowed for an in-depth examination of secondary school teachers' TPACK knowledge about the educational use of mobile devices, taking into account personal and contextual factors.

In this study, mobile devices are considered a cross-cutting theme, as they represent key tools in today's learning environments. Previous evidence highlighting their positive impact on academic achievement, the promotion of autonomous learning, and their contribution to reducing the digital divide[39,40] supports their inclusion in the methodology.

From a quantitative perspective, a survey design was used, and a structured questionnaire with a Likert scale was applied. This instrument was designed to measure teachers' technological, pedagogical, and disciplinary knowledge by the TPACK model and to collect sociodemographic data such as age, gender, academic level, professional experience, ICT training, and availability of support staff in schools.

In the qualitative component of the study, a phenomenological approach was adopted to deepen the understanding of teachers' technological, pedagogical, and disciplinary knowledge from the perspective of school principals. To this end, semi-structured interviews were conducted with principals of schools selected for their participation in the quantitative phase of the study.

Although the central focus of the research was the analysis of teachers' TPACK knowledge, the inclusion of interviews provided access to institutional perceptions that helped interpret the statistical results, providing a broader view of the factors that influence the development of this competence in real teaching contexts.

The research was carried out in Regional Office 08 of the Ministry of Education in Santiago, Dominican Republic. This jurisdiction covers 120 public secondary schools distributed across different areas: urban, marginal urban, rural, and isolated rural.

A non-probability convenience sample was used. The questionnaire was distributed via a digital form and emailed to principals and teaching coordinators, who shared it with their teams through institutional messaging networks. Participation was voluntary and anonymous. Responses were received from 354 teachers from 31 educational centers, representing 19 % of the total teacher population and 26 % of the centers in the region.

The profile of the teachers who completed the questionnaire shows that 62,7 % work in urban areas and 23,7 % in marginal urban contexts. Sixty-two percent of respondents were women, and 38 % were men. The majority (80 %) are between 25 and 44 years old, while 19 % are over 45. Regarding academic training, 64 % have a bachelor's or engineering degree, 33 % have a master's degree, and 3 % have a specialization, indicating that 36 % of teachers have postgraduate studies.

To broaden the understanding of the phenomenon studied from an institutional perspective, semi-structured interviews were conducted with 26 secondary school principals selected from those whose teachers participated in the quantitative phase. The participants represented schools in different geographical contexts—urban, marginal urban, and rural—which allowed for identifying diverse views on teachers' technological, pedagogical, and disciplinary knowledge.

Regarding the profile of the principals interviewed, 38,5 % work in schools in urban areas, another 38,5 % in marginal urban areas, and 23,1 % in rural areas. The distribution by gender was equitable: 50 % women (13) and 50 % men (13). Regarding the length of time in management, 73 % indicated that they had between 5 and 14 years of experience, while 27 % said they had less than 5 years in the position.

Information gathering tools

Initially, data collection was carried out using a questionnaire adapted from the original instrument proposed to evaluate the TPACK model (13), which was specifically adjusted to meet the objective of this research. The instrument consisted of two sections. The first section collected general information about the participants, including variables such as gender, age, academic level, ICT training, years of teaching experience, educational center location, and technological support staff availability. The second section was designed to measure teachers' technological, pedagogical, and disciplinary knowledge using the TPACK model. This section included 19 items organized on a five-point Likert scale (1 = strongly disagree; 5 = strongly agree).

An exploratory factor analysis (EFA) was applied to validate the instrument's structure, which yielded an excellent sample adequacy index (KMO = 0,939) and explained 59 % of the total variance. The items were grouped into a single factor, identified as TPACK Knowledge, with very high reliability (α = 0,954). Subsequently, a principal component analysis confirmed the presence of a unidimensional structure. Table 1 presents the descriptive statistics, factor loadings, and reliability of each item, as well as the teachers' Technological Knowledge scale. The items are organized from highest to lowest in the table according to their factor loadings.

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Table 1. Descriptive statistics, factor loadings, and reliability of each item and factor of the teacher technological knowledge scale according to the TPACK model

No.	Factors	Average	DE	Factor loads	Alpha
I	TPACK	75,008	15,153		0,954
TPACK2	I know how to select digital technologies for use in the classroom that enhance the subject I teach, the way I teach it, and what students learn.	4,229	0,965	0,881	
TP3	My training as a teacher has made me think more carefully about how technology can influence the teaching approaches I use in the classroom.	4,020	1,000	0,864	
TP2	I know how to select technologies that enhance student learning in a classroom setting.	3,989	1,035	0,858	
TPACK1	I can deliver lessons that appropriately combine the content I teach, technologies, and teaching approaches.	4,186	0,955	0,852	
TPACK5	I can select digital technologies that enhance lesson content.	4,073	0,973	0,838	
TP4	I think critically about how to use technology in the classroom.	4,088	0,982	0,836	
TP5	I can adapt the use of digital technologies I am learning about to different teaching activities.	4,229	0,935	0,830	
TPACK4	I can guide and help others to coordinate the use of content, digital technologies, and teaching approaches in my school and/or administrative region.	3,958	1,033	0,811	
TEC6	I am familiar with different technological tools.	4,054	1,024	0,793	
TP1	I know how to select technologies that improve teaching approaches for a class.	3,621	1,189	0,786	
TPACK3	I know how to use strategies that combine content, digital technologies, and teaching approaches I have learned in my classroom teaching materials.	4,130	0,967	0,773	
TEC4	I often use technology in my classroom practice.	4,175	0,948	0,773	
TK	I am familiar with digital technologies that I can use to understand and develop content for the subject I teach.	3,949	1,120	0,761	
TEC8	I have had sufficient opportunities to work with a variety of technologies.	3,893	1,136	0,757	
TEC7	I have the technical knowledge I need to use technology.	3,720	1,153	0,734	
TEC5	I frequently test the technology I use in my classroom.	3,907	1,056	0,710	
TEC3	I keep up to date with important new digital technologies.	3,754	1,082	0,680	
TEC2	I assimilate technological knowledge easily.	3,751	1,396	0,469	
TEC1	I know how to solve my technical problems.	3,282	1,398	0,362	

To confirm the structure identified by exploratory factor analysis, confirmatory factor analysis (CFA) was performed. The results showed a goodness-of-fit index (GFI) = 0,991, a root mean square error of approximation (RMSEA) = 0,046, and a standardized root mean square residual (SRMR) = 0,062. Figure 2 shows the structure of the proposed model.

A semi-structured interview script was designed for school principals to complement the data obtained through the questionnaires. This instrument allowed us to explore, from an institutional perspective, aspects related to teachers' technological, pedagogical, and disciplinary knowledge. The interviews were conducted with the 26 principals of the schools selected in the sample.

The instrument was organized into three sections comprising 12 open-ended questions. The first part addressed general aspects of the principals' profiles, such as length of service and professional experience. The second included questions about their familiarity with using mobile devices in education. The third section focused on teachers' perceptions of the implementation of these technologies, the tools used, TPACK knowledge, the training received, and the main institutional barriers.

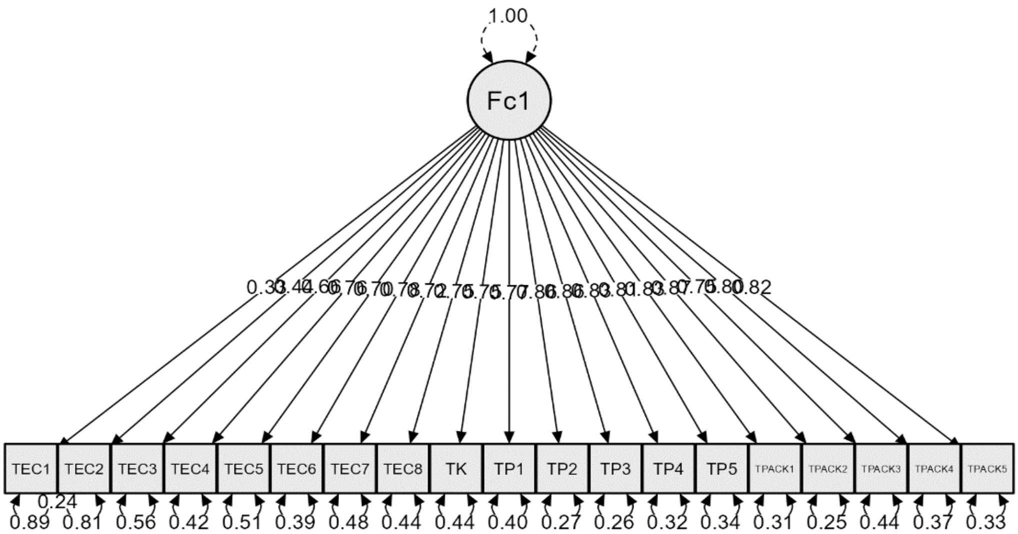


Figure 2. Structure of the Knowledge Scale

To ensure the instrument's validity, a content validation process was carried out through expert judgment. Five specialists participated in this review. Based on their observations, modifications were made to improve clarity, internal consistency, and the appropriateness of technical language.

To validate the category system used for analyzing the interviews, we reviewed three representative interviews from different school contexts (urban, marginal urban, and rural). This process allowed us to verify the relevance and reliability of the proposed category system.

The analysis of the interviews was structured using a deductive approach based on the theoretical framework and the dimensions derived from the questionnaire—a priori established the main categories and subcategories. However, the system also incorporated elements that emerged during the coding process, allowing new findings to be integrated directly from the participants' discourse.

Data Analysis

Descriptive statistics, such as frequencies, percentages, means, and standard deviations, were used to present the demographic and general characteristics of the participants. To examine whether variables such as gender, age, academic level, years of experience, ICT training, and institutional support influence teachers' TPACK knowledge level, Student's t-tests and analysis of variance (ANOVA) were applied, as appropriate, with a significance level of 5 %.

The quantitative analysis included t-tests to compare TPACK knowledge scores based on teachers' gender, the existence of technological support staff in the schools, and participation in ICT training processes. ANOVA was also used to explore possible differences in TPACK knowledge levels according to the schools' age, academic level, and geographical location. These analyses identified significant patterns that contributed to achieving the study's primary objective.

Regarding the qualitative component, the interviews were analyzed using a thematic analysis approach using MAXQDA software. Coding was initially performed using a deductive approach based on the theoretical dimensions of the TPACK model.

Although this study focused on TPACK knowledge for the pedagogical use of mobile devices, its findings can be extended to ubiquitous learning contexts. This approach, facilitated by these devices' portability and connectivity, forms the basis of emerging scenarios such as the metaverse, where the TPACK model remains key to teacher preparation.

RESULTS

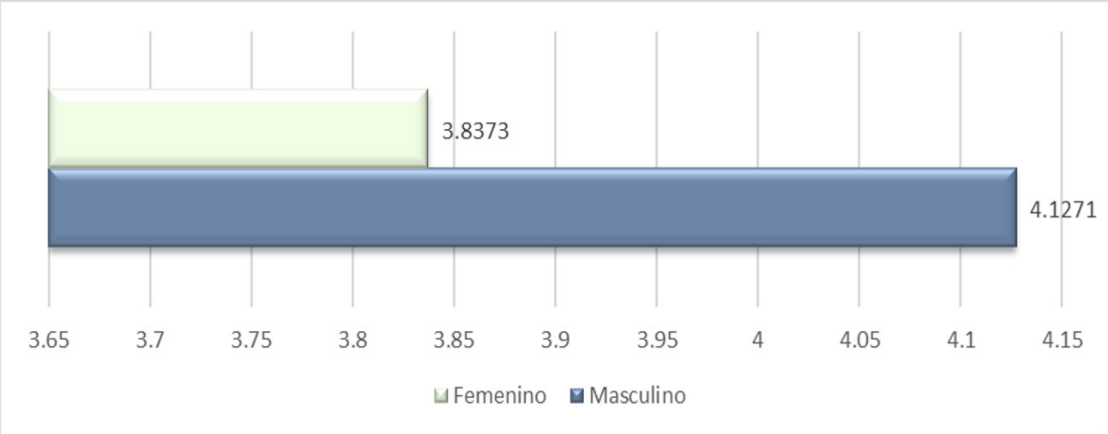
The triangulation of quantitative and qualitative data allowed us to describe teachers' level of TPACK knowledge and explore the factors that influence its development according to school principals' perceptions. This methodological combination provided a more comprehensive view of the phenomenon studied. The main findings are presented below and organized by type of data.

Quantitative results on teachers' TPACK knowledge

This section presents the results of the questionnaire administered to 354 secondary school teachers to assess their level of TPACK knowledge. Descriptive analyses (means, standard deviations, frequencies, and percentages) were used to characterize the overall level of expertise, as well as inferential tests (Student's t-test and ANOVA) to explore differences according to personal and contextual variables (gender, age, academic level, geographical area, years of service, ICT training, and institutional support). These findings provide insight into the level of TPACK knowledge and its variability depending on conditions relevant to the pedagogical use of mobile technologies.

According to the scale used and the responses of the 354 teachers surveyed, the Knowledge variable obtained an overall average of 3,95 in its single dimension, which places it at a moderately high level.

To analyze possible differences based on gender, an independent samples t-test was performed, comparing the scores obtained on the Knowledge scale in its single dimension. The results, shown in figure 3, indicated a statistically significant difference (t(352) = 3,369, p = 0,001), with a small effect size (d = 0,37) and low test power (1 - ß = 0,574). These differences indicate that male teachers obtained higher scores than their female colleagues, implying a higher level of technological knowledge according to the TPACK model.



Source: questionnaire administered to teachers at secondary schools in regional district 08.
Figure 3. Averages in the dimension Technological knowledge of teachers by gender of teaching staff

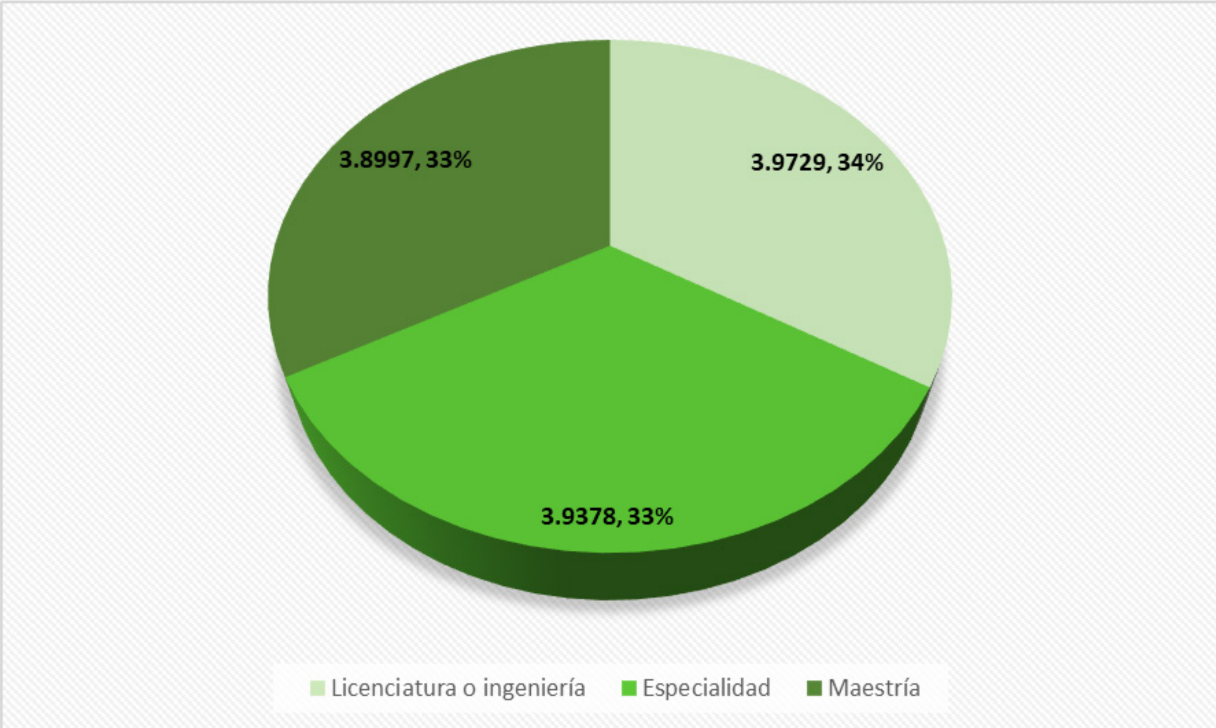
Regarding age group, ANOVA showed a statistically significant difference, F (7,346) = 2,791, p = 0,008, with a small effect size (f = 0,1881). Applying the Bonferroni correction, multiple comparisons revealed that participants aged 30 to 34 obtained slightly higher means than those aged 35 to 39, indicating greater TPACK knowledge for technology integration. These results are presented in table 3.

Table 3. Descriptives in the Technological Knowledge dimension of teachers (TPACK) by teacher age

		Academic uses	
Ages	**N**	**Average**	**Standard deviation**
Under 25 years old	4	4,0263	0,34513
25 to 29 years old	65	4,1498	0,65203
30 to 34 years old	54	4,2456	0,51507
35 to 39 years old	81	3,7953	1,00497
40 to 44 years old	84	3,8221	0,70966
45 to 49 years old	25	3,9305	0,78885
50 to 54 years old	30	3,7386	1,00761
55 years old or older	11	3,9569	0,62666
Total	354	3,9478	0,79753

Source: questionnaire administered to teachers at secondary schools in regional district 08

In contrast, the analysis of variance (ANOVA) performed on the academic level did not show statistically significant differences between the different levels, F (2,351) = 0,323, p = 0,725 (figure 4). It can therefore, be concluded that there are no significant differences in teachers' knowledge (TPACK) based on their academic level.



Source: questionnaire administered to teachers at secondary schools in regional district 08.
Figure 4. Descriptives in the technological knowledge dimension (TPACK) according to teachers' academic level

Unlike the academic level, ANOVA on teachers' years of service showed statistical significance, F (6,347) = 3,013, p = 0,007, with a medium effect size (f = 0,185). The differences identified in the multiple comparisons, with Bonferroni correction, indicate that participants with less than 5 years of service showed moderately higher means than those with 20 to 24 years, demonstrating greater knowledge of technology, as shown in table 4.

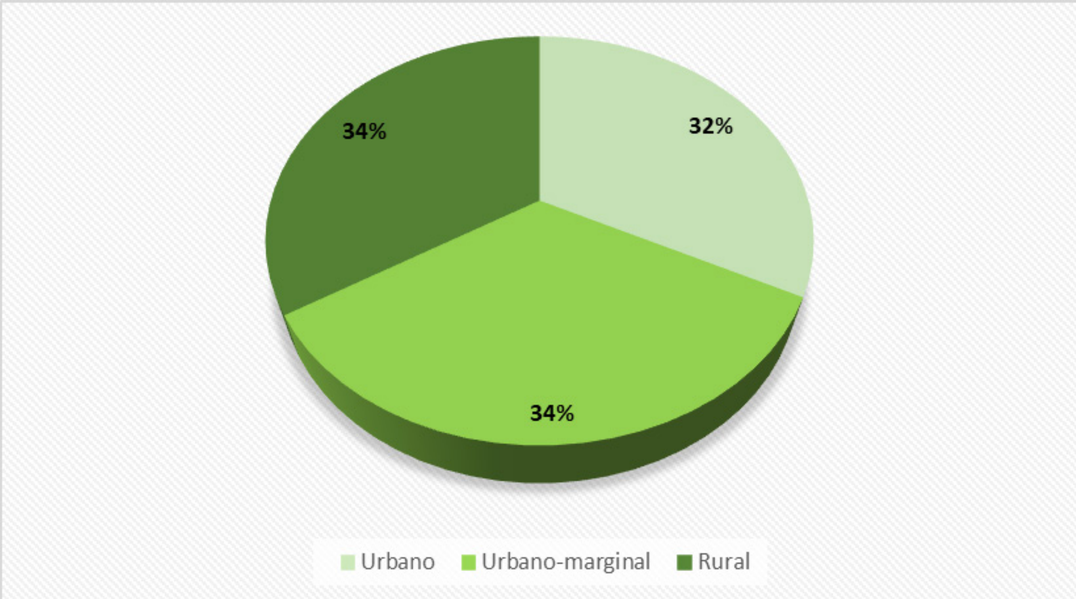
Table 4. Descriptives in the Technological Knowledge dimension (TPACK) by years of service of teachers

Years in service	TPACK knowledge		
	N	Average	Standard deviation
Under 5 years old	135	4,0912	0,61638
5 to 9 years old	119	3,9828	0,83153
10 to 14 years old	46	3,7025	1,12698
15 to 19 years old	25	3,7600	0,84567
20 to 24 years old	21	3,5038	0,56258
25 to 29 years old	5	4,1474	0,16809
30 years old or older	3	4,2105	0,27348
Total	354	3,9478	0,79753

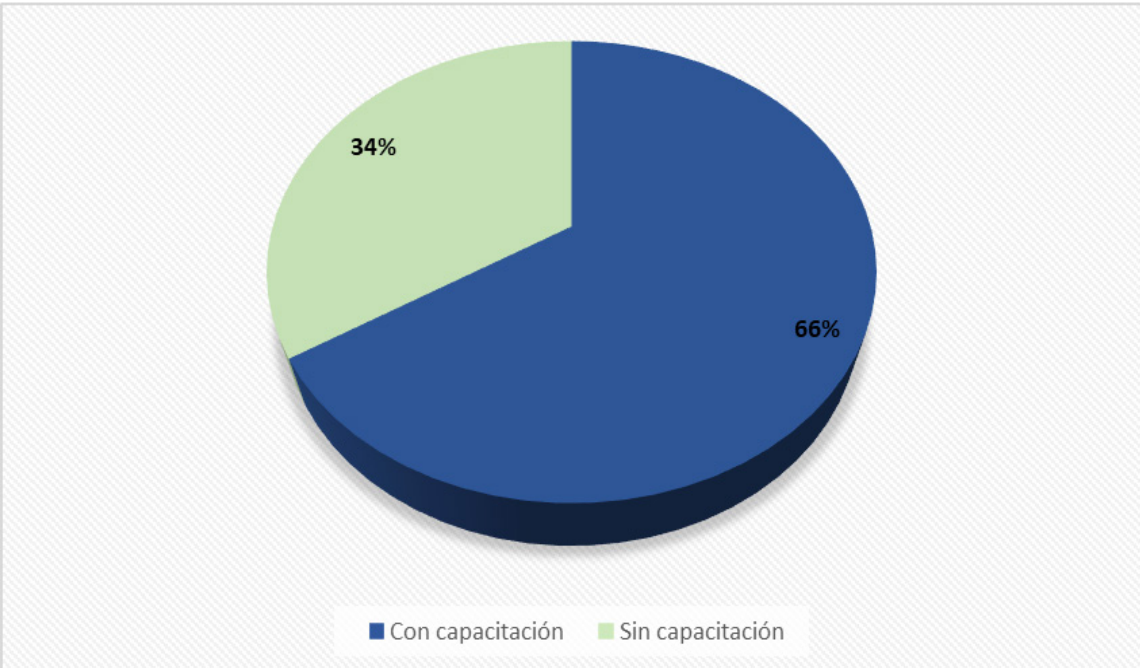
Source: questionnaire administered to teachers at secondary schools in regional district 08.

On the other hand, the ANOVA variance analysis performed on the location of the educational center did not show statistically significant differences between the different areas F (2,351) = 1,813, p = 0,165 (figure 5). This indicates that geographical location is not a differentiating factor in teachers' TPACK knowledge.

Likewise, to identify possible statistically significant differences in the mean knowledge scores (TPACK) between teachers who have received technology training and those who have not an independent samples t-test was performed, assuming equal variances (F= 0,901, P > 0,05). The results indicate significant differences between the two groups, showing that teachers who have received training have greater technological knowledge (TPACK) compared to those who have not been trained (t =8,301, gl = 352, P < 0,000), as shown in figure 6.

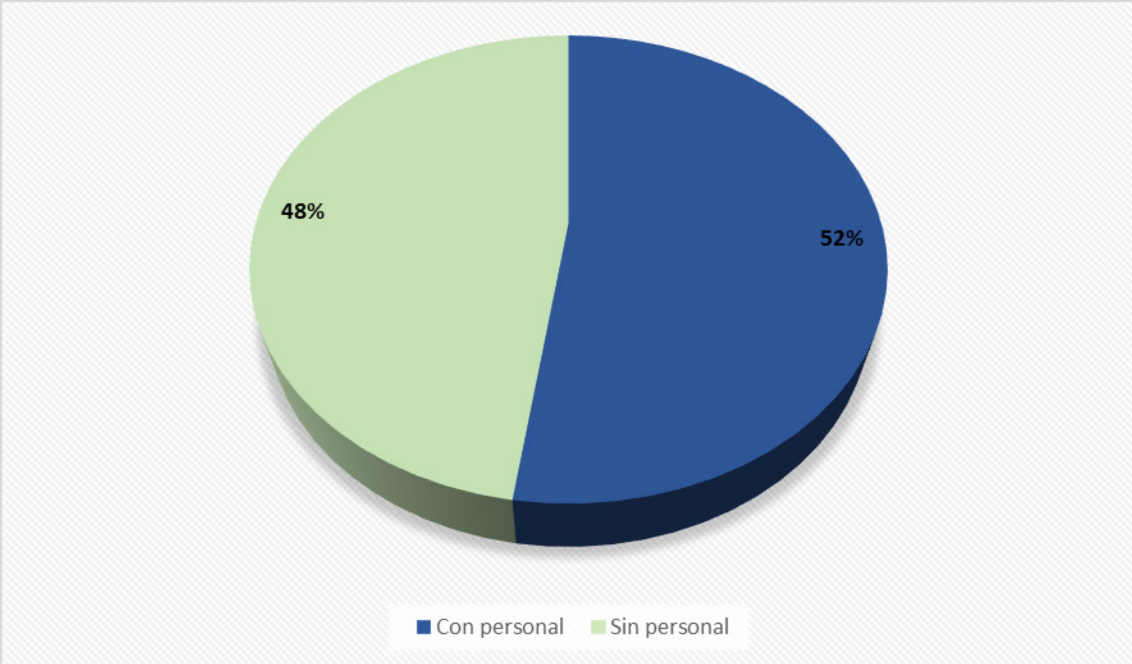


Source: auestionnaire administered to teachers at secondary schools in regional district 08.
Figure 5. Descriptives in the variable Teachers' technological knowledge (TPACK) by school location



Source: questionnaire administered to teachers at secondary schools in regional district 08
Figure 6. Descriptives in the technological knowledge dimension of teachers (TPACK) according to the ICT training received by teachers

Similarly, we examined whether the presence of support staff at the school influenced teachers' level of technological knowledge. We performed an independent samples t-test, assuming equal variances (F = 0,247, p > 0,05). The results showed significant differences (t = 2,871, gl = 352, p = 0,004), with a medium effect size (d = 0,45) and adequate test power (1- β = 0,8889). In this sense, teachers who had support staff, such as facilitators from the República Digital program or ICT facilitators, had greater technological knowledge compared to those who did not have this resource, as illustrated in figure 7.



Source: questionnaire administered to teachers at secondary schools in regional district 08
Figure 7. Descriptives in the Technological Knowledge dimension of teachers (TPACK) based on the availability of staff in the school to support teachers in the integration of ICT

Qualitative results: principals' perceptions of teachers' TPACK knowledge

Semi-structured interviews with 26 school principals supplemented the questionnaire data, providing an institutional perspective on teachers' TPACK knowledge levels. Thematic analysis identified four subcategories corresponding to the model's dimensions: technological knowledge (TK), pedagogical knowledge (PK), technological content knowledge (TCK), and pedagogical technological knowledge (TPK). These dimensions were addressed based on the principals' daily experiences and observations of their teachers.

Technological knowledge (TK)

The principals agreed that many teachers are comfortable using digital tools, educational platforms, and technological resources. They attribute this level of knowledge mainly to training programs promoted by the Ministry of Education, such as República Digital:

"Teachers have received training in República Digital to use technological tools "(Participant 26).

" The Ministry of Education played its role very well in providing the necessary training to teachers to use the different digital tools used in schools" (Participant 15).

In addition, they highlighted that some teachers already had technological skills before the training, which fostered collaboration among peers:

"Some teachers with certain skills [...] tried to strengthen their colleagues in this regard" (Participant 23).

"Some teachers already had prior knowledge of technology, which they have used to support and train their colleagues" (Participant 21).

Pedagogical knowledge (PK)

Regarding teaching practices, principals recognize that there are teachers who apply varied and effective strategies in their classrooms, especially in areas such as mathematics and natural sciences:

"In mathematics, it is good because teachers explain and use different strategies to explain these topics, as in natural sciences" (Participant 3).

Technological content knowledge (TCK)

This subcategory reflects how teachers combine technology with curriculum content to facilitate student understanding. A concrete example was observed in the area of natural sciences:

"In natural sciences, applications allow microscopic elements to be viewed interactively" (Participant 5).

Pedagogical technological knowledge (PTK)

Principals also noted that the pedagogical use of technology intensified during the pandemic, thanks to training programs implemented at the national level. These trainings allowed teachers to develop key competencies for virtual teaching:

"They received training on how to use the devices, as well as different applications in the classroom and how to develop some classes using those applications" (Participant 16).

"During the pandemic, tools such as Moodle, Classroom, and Zoom were used to facilitate education "(Participant 22).

" Yes, they received excellent training during the pandemic, which developed the technological skills of teachers to deliver distance learning" (Participant 9).

However, persistent limitations were also identified. One of the principals commented:

"Yes, teachers have taken training, but I understand they are still very, very behind in the digital area" (Participant 14).

DISCUSSION

The quantitative results identified significant differences in teachers' TPACK knowledge levels according to gender, age, years of service, and access to training. These findings were complemented by qualitative data obtained from interviews, which provided a more contextualized view of the institutional conditions that influence the development of these competencies. The triangulation of both approaches allowed for a more comprehensive understanding of the phenomenon.

Using mobile devices in classrooms is a technological innovation and a real opportunity to transform teaching practices when properly articulated with TPACK knowledge. Qualitative evidence shows that, in many cases, continuous training and collaborative work have facilitated their integration.

TPACK has proven effective in assessing and developing technological competencies in secondary school teachers.

The results show that teachers obtained an average score that places their TPACK knowledge high. This suggests they adapt their teaching to diverse technological contexts and critically evaluate digital tools before applying them. However, as Schmid et al.[16] point out, this knowledge has not yet been fully consolidated due to limited practical experience. Some teachers and principals noted that training programs and peer support have strengthened technological knowledge.

Although teachers' TPACK knowledge scores are high, they are not yet perfect,[5] with some variables influencing this, as explained below. Statistically, there is no significant variation in TPACK knowledge levels among teachers with different academic degrees (e.g., bachelor's, master's, or doctorate). These results contradict those presented by Shiri et al.[29], who concluded in a study that a higher academic level is associated with a higher level of TPACK knowledge.

On average, male teachers have a higher level of knowledge than female teachers. These results are consistent with those of a study conducted by Gómez-Trigueros et al.[28], who show significant differences between men and women in all components of TPACK, with men scoring higher. These differences reflect a persistent gender gap in teacher training in digital skills.

Teachers aged 30 to 34 show a slightly higher level of TPACK knowledge than those aged 35 to 39, although with a small effect size, so the results should be interpreted cautiously. This difference could be due to more recent training aligned with emerging technologies and greater personal and professional exposure to these tools. Similarly, a moderate difference in technological knowledge was identified between teachers with less than 5 years of service and those with 20 to 24 years of experience, with the former having higher levels. This implies that more recent initial training favors better integration of technologies, while teachers with more experience rely more on continuous learning.

Teachers who have participated in training show a higher level of TPACK knowledge than those who have not, which is why continuous training is essential to strengthening their technological, pedagogical, and content competencies, as suggested by various researchers.[15,25,26,30,32] Teachers with specific training are better prepared to integrate technology, pedagogy, and content into their educational practices.[31] TPACK knowledge can be significantly enhanced through continuing education.

This quantitative finding is supported by the school principals' perceptions, who agreed that many teachers have strengthened their technological knowledge thanks to training programs such as República Digital and support from colleagues. These qualitative observations help to contextualize the scores obtained in the questionnaire and show how TPACK knowledge is also built from an institutional and collaborative perspective.

In interviews with principals, they said that most of the educational technology training offered by the Ministry of Education took place during the pandemic. Understandably, a lot of time has passed, making it necessary to implement new ongoing technology training projects for teachers.

Similarly, the questionnaire data showed that the support provided by specialized staff has a moderate but significant impact on teachers' TPACK knowledge, which is supported by statistically robust evidence. This information is consistent with a study conducted by Maipita et al.[33], who found that, in addition to TPACK, institutional support is needed to integrate technologies successfully.

The Dominican government must invest in support staff as a key strategy for strengthening technological integration in teaching and improving teacher performance in the current educational context. With support staff for technology integration, teachers receive guidance on using technological tools in the classroom and integrating them into their lesson plans. As principals express in interviews, these staff members provide timely and personalized training on using technological tools and innovative methodologies. In addition, they help resolve technical issues quickly, reducing barriers to technology use. This support can improve teachers' confidence in using technology and foster a more positive attitude toward its integration.

As educational environments transform toward more interactive, immersive, and digitized models, mobile learning represents a key gateway to new forms of teaching. This study suggests that developing TPACK knowledge strengthens the integration of mobile devices in the classroom and lays the foundation for future incorporations of emerging technologies such as artificial intelligence, augmented reality, and immersive ecosystems typical of the metaverse. These technologies, like mobile devices, require teachers with integrated skills in technology, pedagogy, and content. In this sense, the TPACK model can become a transition tool for teachers preparing to design learning experiences in three-dimensional virtual environments with avatars, simulations, adaptive intelligence, and synchronous collaboration.

Investing in TPACK training for teachers responds to current needs. It is a fundamental strategy for advancing toward an education connected to the educational metaverse, where learning will become increasingly ubiquitous, personalized, interactive, and multimodal.

In summary, this study reveals that secondary school teachers have a moderately high level of TPACK knowledge, constituting a solid foundation for the pedagogical integration of mobile devices in the classroom. However, variables such as gender, age, years of service, training, and institutional support significantly influence the development of these competencies. These findings highlight the need to implement differentiated and contextualized continuing education programs and strengthen technical support in schools. Future research should explore how these dimensions of TPACK knowledge manifest in teaching practice and how they evolve over time and with technological advances.

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FINANCING

None.

CONFLICT OF INTEREST

Authors declare that there is no conflict of interest.

AUTHORSHIP CONTRIBUTION

Conceptualization: Dilenia A. Marte Marte.
Data curation: Dilenia A. Marte Marte.
Formal analysis: Dilenia A. Marte Marte.
Drafting - original draft: Dilenia A. Marte Marte.
Writing - proofreading and editing: Dilenia A. Marte Marte.