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RESEARCH ARTICLE

From Measuring to Action: The Next Steps in Physics Teachers' Technological Pedagogical Content Knowledge

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ABSTRACT

The Technological, Pedagogical Content Knowledge (TPACK) model serves as a comprehensive conceptual framework that delineates the essential knowledge domains teachers must possess to effectively integrate technology within educational settings. By synthesizing technological knowledge, pedagogical knowledge, and content knowledge, TPACK empowers educators to create innovative, engaging, and meaningful learning experiences that cater to diverse student needs. Extensive research has indicated that teaching practices informed by the TPACK framework can significantly enhance student motivation, foster critical thinking skills, and improve overall academic performance. Moreover, the successful implementation of TPACK is contingent upon several critical factors, including ongoing professional development opportunities for educators, the availability of adequate technological resources, and the cultivation of a supportive school culture that encourages collaboration and experimentation. A recent paper presents, the results of a quantitative study conducted using the TPACK questionnaire. Data are collected utilizing the database of the Association of Physics Teachers of Georgia. Confirmatory factor analysis for the constructs' reliability is conducted. The results of the factor analysis are grouped into four factors, which differ from those in other studies and are discussed below. Based on these findings, recommendations are provided for the improvement and integrating technology into physics teacher education.

KEY WORDS: Physics teachers; Technological pedagogical content knowledge; Technology

INTRODUCTION

In recent decades, the rapid development of technology has necessitated changes in the educational process. The learning process has become more dependent on digital standards. This, in turn, led to the need to reassess teachers' readiness to cope with new challenges (Peters et al., 2022). It became necessary for teachers not only to have subject-specific competencies but also to improve their technological skills. For this reason, to increase the effectiveness of the teaching-learning process, the Ministry of Education and Science of Georgia (South Caucasian Republic) has set one of its key objectives as the integration of Information and Communication Technologies (ICT) in general education at schools (Document in Georgian language).[1]

The urgency of this issue was highlighted once again by the COVID-19 pandemic when the education system suddenly faced the major dilemma of transitioning the entire learning process to a fully remote mode. At that time, however, there was insufficient preparedness in many countries (Daniel, 2020; Tarkar, 2020; Özüdoğru, 2021), and in Georgia as well. Based on consultations with subject matter experts (in physics, chemistry, and biology) from the Ministry of Education of Georgia, the situation was addressed as follows: First, a group of volunteer "coaches" was mobilized, who provided assistance to teachers as needed, to ensure the uninterrupted progress of the learning process. The real situation, however, turned out to be quite challenging. There was no technically well-equipped environment, meaning that not all teachers had the necessary technical support, and internet quality was also quite low. In addition to technical problems, certain content-related issues emerged, such as the correct use of software and language barriers (a certain level of English proficiency became necessary). School administrations did not have the necessary resources to address these issues, which had a significant impact on the motivation of both teachers and students - a critical component of the teaching-learning process (document in Georgian language).[2]

A recent paper presents findings on the technological skills of Georgian physics teachers. The motivation behind this research stems from a commitment to improving educational outcomes, addressing regional disparities, preparing students for a technology-driven future, and supporting teachers through tailored professional development (PD).

LITERATURE REVIEW

The technological pedagogical content knowledge (TPACK) framework outlines the types of knowledge teachers need to successfully integrate technology into their teaching,

1 https://matsne.gov.ge/ka/document/view/4841342?publication=0

2 https://mes.gov.ge/uploads/files/zogadi-ganatlebis-xelshecyoba.pdf

representing a critical aspect of modern educational practice (Mishra and Koehler, 2006). At the heart of this framework is the idea that teaching with technology is a complex and dynamic process that requires teachers to understand the interplay between three core knowledge domains: Content Knowledge (CK), Pedagogical Knowledge (PK), and Technological Knowledge (TK). Together, these domains form a comprehensive model for understanding the kinds of expertise teachers must have for meaningful technology integration (Zhang and Tang, 2021).

The TPACK framework has been a key topic in educational research, becoming central to discussions on teacher education and PD. (Putri et al., 2022; Wollmann and Lange-Schubert, 2022; Nilsson, 2024).

Historical Development of TPACK

The roots of the TPACK framework can be traced back to the concept of Pedagogical Content Knowledge (PCK), introduced by Shulman (1986). Shulman's work focused on how teachers need to integrate content knowledge with pedagogy to effectively teach students. He emphasized that teaching is not merely about knowing the subject matter but about knowing how to make that content comprehensible to diverse learners.

In 2001, Pierson (Pierson, 2001) first introduced the concept of TPCK, viewing technology as an essential addition to Shulman's PCK model. Pierson understood TPCK as a collection of knowledge and skills that teachers needed to use technology in subject-specific instruction (Zhang and Tang, 2021). However, in 2005, Niess offered a critique of Pierson's static definition, suggesting that TPCK is a dynamic process (Niess, 2005). According to Niess et al. (2007), TPCK involves the ongoing development of CK, pedagogical understanding, and technological fluency. This marked an important shift, positioning TPCK not as a set of fixed skills but as a constantly evolving integration of knowledge that changes as new technologies and teaching methods emerge (Xu et al., 2013).

At the same time, Koehler and Mishra (2005b) introduced their own understanding of TPCK, which built directly on Shulman's original PCK framework. In their landmark 2006 article, "Technological Pedagogical Content Knowledge: A Framework for Teacher Knowledge," Koehler and Mishra expanded on the dynamic interplay between technology, pedagogy, and content in the teaching process. They argued that effective teaching with technology requires a balance of all three areas and that the ability to integrate technology in a pedagogically meaningful way was the key to modern education (Mishra and Koehler, 2006).

From TPCK to TPACK

In 2007, Thompson and Mishra made a significant change to the TPCK model by renaming it TPACK, a term that reflects a deeper integration of the three knowledge domains (Thompson and Mishra, 2007). The addition of the vowel "A" was not just a stylistic choice; it emphasized the synergy between technological, pedagogical, and CK, implying that these domains do not exist independently but are interconnected in practice. The acronym "TPACK" thus represents a more holistic understanding, where these types of knowledge work together as a cohesive "total package."

This comprehensive approach means that teachers who possess TPACK can effectively design and implement teaching strategies that incorporate technology in ways that are aligned with both the content being taught and the pedagogical needs of their students. TPACK transcends the simple use of technology for its own sake and focuses instead on how technology can enhance learning experiences by aligning with pedagogy and content.

Contextual Knowledge (XK) and the Expanding TPACK Framework

In recent years, Mishra (2019) introduced an extension to the TPACK framework by adding XK. This recognizes that teachers' knowledge of the context in which they are teaching is a critical component of effective technology integration. Contextual factors may include the students' backgrounds, the school's infrastructure, the community, and the cultural and socio-economic setting in which teaching takes place. According to Mishra, the "X" in XK represents the variable and changing nature of context, acknowledging that contextual factors are not static and can rapidly shift (Mishra, 2019).

This expansion is particularly relevant in today's educational landscape, where technology is becoming more accessible but also more diverse, and where educators must adapt their practices to fit specific learning environments. For example, the technology available in well-resourced schools differs greatly from that in under-resourced schools, affecting how teachers can integrate technology into their lessons. Furthermore, during crises such as the COVID-19 pandemic, teachers had to adapt to rapidly changing contexts, such as moving from face-to-face to online learning environments, which underscored the importance of context in technology integration (Trust and Whalen, 2020; Daniel, 2020;).

Application and Impact of TPACK in Education

Research shows that the TPACK framework has had a significant impact on teacher education programs and PD initiatives around the world. Several studies (Graham, 2011; Yeh et al., 2015; Memiş et al., 2023) emphasize the need for teacher preparation programs to focus on developing TPACK, as many teachers begin their careers with limited experience in integrating technology into their instruction. To address this, many programs have incorporated hands-on, technology-rich learning experiences into their curricula to help pre-service teachers develop the skills needed to effectively use technology in the classroom.

In practice, TPACK has been applied across a range of subject areas and educational levels. As technology becomes more prevalent in classrooms and the demand for TPACK grows, teachers should focus on enhancing the quality of their ICT-integrated instruction, rather than simply aiming to incorporate ICT tools into their teaching (Yeh et al., 2015). Studies have shown that teachers with well-developed TPACK are better equipped to use technology in ways that improve student learning outcomes. For example, in science education, the use of simulations and digital labs has enabled students to visualize complex scientific concepts that are otherwise difficult to grasp. In language arts, digital storytelling tools and online discussion platforms have provided new ways for students to engage with texts and collaborate with their peers (Potkonjak et al., 2016).

Despite these successes, the implementation of TPACK is not without challenges. Many teachers struggle with balancing technology integration with pedagogy and content, particularly when faced with limited resources or a lack of PD opportunities. Kimmons (2015) highlights the systemic barriers, such as insufficient access to technology or inadequate time for training, which can prevent teachers from fully realizing their TPACK potential.

Numerous studies explore the application of TPACK in education. Many educational institutions incorporate TPACK into teacher training programs. Initiatives often focus on developing teachers' abilities to effectively integrate technology in their classrooms (Mishra and Koehler, 2006). TPACK can also guide curriculum developers to create learning experiences that utilize technology in innovative ways while aligning with pedagogical best practices and content standards (Angeli and Valanides, 2009). Educators apply TPACK to assess their own teaching styles and refine their approach, ensuring that technology is used meaningfully to support teaching and learning (Ertmer and Ottenbreit-Leftwich, 2010).

Research has shown that integrating TPACK into educational practice can lead to several positive outcomes. Koehler and Mishra (2013) highlighted advancements in teaching practices. Teachers who utilize the TPACK framework often report enhanced confidence and competence in their ability to integrate technology into their lessons.

Studies have indicated that TPACK-informed instruction can lead to improve student performance, as the thoughtful integration of technology can facilitate a deeper understanding of content (Voogt and Roblin, 2012).

TPACK serves as a valuable framework in the field of education, facilitating the effective integration of technology into teaching. Its application across various countries has demonstrated positive impacts on teaching practices, student engagement, and learning outcomes.

In a case study, TPACK-based courses showed that pre-service teachers developed stronger technology integration skills, with increased confidence in integrating digital tools into their instruction effectively in the USA. Such studies emphasize TPACK's role in bridging technology with content and pedagogy, particularly benefiting STEM fields by enhancing student engagement and achievement (Eshelman and Hogue, 2023).

Research highlights a positive link between TPACK self-efficacy and technology integration among pre-service teachers in Turkey. Those with higher confidence in TPACK frameworks tend to use technology in more pedagogically meaningful ways, suggesting that TPACK training supports effective digital teaching practices (Dewi et al., 2021).

In Australia TPACK adoption within teacher education programs is associated with more reflective teaching practices and enhanced pedagogical adaptability. Educators in Australia have found that integrating TPACK leads to improvements in adjusting technology use to specific learning contexts, allowing for more personalized student experiences (Phillips and Harris, 2018).

TPACK application aligns technology with pedagogical strategies in ways that support student learning outcomes across disciplines. Studies report that Korean teachers effectively match digital tools to instructional goals, leading to increased student success and engagement (Chai et al., 2013).

Finland's focus on TPACK has contributed to innovative teaching practices, emphasizing student-centered learning. Finnish educators leverage TPACK to foster collaboration and adaptability, aligning well with Finland's progressive educational framework (Ilomäki and Lakkala, 2018).

Continued research and development of TPACK-centered PD can further enhance its effectiveness in diverse educational settings. Further research is needed to advance teachers' PD in multiple other aspects.

Future Research Directions

The TPACK framework continues to evolve as new technologies emerge and educational environments change. Future research will need to focus on how emerging technologies, such as artificial intelligence, virtual reality, and augmented reality (Abdullah et al., 2023), can be incorporated into the TPACK model. In addition, more research is needed on how to support teachers in developing their TPACK over time, especially as they face the challenges of rapidly changing educational contexts and technologies.

Ultimately, studying TPACK skills in Georgia provides a critical foundation for building a modern, resilient education system that is capable of meeting the diverse needs of students and preparing them for a technology-driven world.

METHODOLOGY

Research Question and Instrument

It is likely that at least some of the challenges that teachers in Georgia encountered during COVID-19 stemmed from a lack of confidence in utilizing digital tools and adapting to remote teaching. For many, the sudden shift to online learning posed significant challenges, as teachers had to quickly adapt to new technologies, rethink lesson delivery, and manage student engagement from a distance. In some cases, a lack of prior training or familiarity with digital platforms may have further compounded these difficulties, making it harder for teachers to feel confident and effective in an online environment.

In addition, the transition may have exposed gaps in both technological infrastructure and digital literacy skills, not only for teachers but also for students and parents. Limited access to reliable internet and devices, especially in rural or underserved areas of Georgia, created an added barrier, intensifying the challenges faced by educators. As a result, teachers may have experienced higher levels of stress and frustration, impacting their overall confidence and effectiveness in delivering quality education.

The TPACK model is used as a theoretical framework for the presented study. It consists of three main elements, subject knowledge (CK), PK, and TK, as well as 4 complex elements, pedagogical and subject knowledge (PCK), technological and subject knowledge (Technological content knowledge [TCK]), technological and pedagogical knowledge (TPK), and also technological, pedagogical and subject knowledge (TPACK). The content (Koehler and Mishra, 2008), is presented in Figure 1.

Based on this model, CK defines the knowledge of the teachers who are responsible for the basic teaching of the subject. PK defines knowledge of the category of teachers who possess an understanding of educational practices, strategies, and methods through which they can encourage students during the learning process. TK defines knowledge of a group of teachers who successfully integrate traditional methods as well as new technologies into the curriculum.

TPACK is represented by the intersection of these domains, highlighting the need for teachers to integrate technology with pedagogy and content. This framework helps educators assess their skills and develop strategies for fostering 21st-century learning environments.

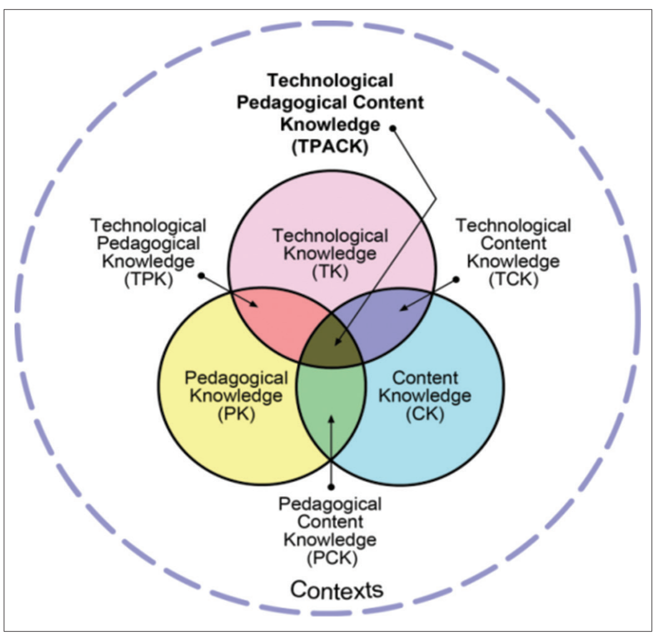

Figure 1: Technological pedagogical content knowledge model (http://tpack.org/)

Using this model, the research question of the present study is as follows: How confident are in-service physics teachers in each of the four TPACK constructs?

For conducting a quantitative study, a TPACK questionnaire was used (Graham et al., 2009), (Appendix 1). The preparatory stage involved translating and adapting the questionnaire to the Georgian context. Defining the specificity of the questionnaire and adapting it to the Georgian reality is crucial for accurate information analysis. To this end, the experiences of other countries was reviewed and considered (Graham, 2009).

Data Collection

For collecting data, the database of the "Association of Physics Teachers of Georgia" is used. This association was established in 2023 and aims to promote the teaching and learning of physics and create new opportunities for the PD of physics teachers in the country. Its' database has been created and currently includes over 400 physics teachers. Participant teachers are from state and private schools, from rural and urban regions of Georgia. Their ages ranged from 22 to 75 years old. Accordingly, their teaching experience also varies for everyone. There are beginner teachers, those with 1 year of experience, and also those with over 30 years of experience.

The translated and adapted TPACK questionnaire is used for the data collection. It is noteworthy that 33% of association members participated in the survey.

FINDINGS

We received a total of 135 responses, with 4 main constructs identified (TPCK, TPK, TCK, TK), and we had a total of 31 variables. For data processing, R and SPSS were used. At the initial stage, an analysis of the constructs' reliability was conducted - confirmatory factor analysis using the R libraries Lavaan and SemTools.

The questionnaire incorporated several scales to assess respondents' confidence across various dimensions of TK. Each item was rated using a six-point Likert scale, reflecting the degree of confidence as follows: 1="Not confident at all", 2="Slightly confident", 3="Somewhat confident", 4="Fairly confident", 5="Quite confident", 6="Completely confident". TCK items only had a 0="I don't know about this kind of technology". Cronbach's alpha was calculated to determine internal consistency reliability for the constructs using the combined pre- and post-data with the following results (Table 1):

These results suggest that the measurement tool is highly reliable, with all constructs demonstrating a Cronbach's alpha >0.90, which indicates excellent internal consistency (Nunnally and Bernstein, 1994). Therefore, the scales used in this study show a very high level of reliability, making them suitable for assessing confidence in TPACK-related knowledge domains.

Due to the limited number of participants in the study, we recognized that establishing construct validity through item analysis techniques would not be feasible. However, content validity for the survey items is grounded in definitions and descriptions from the TPACK and PCK literature (Cavin, 2008). The wording of each survey item and descriptive statistics at both the item and construct levels are provided in the findings to allow readers to assess their confidence level in the results.

Upon confirming the reliabilities of the constructs – TPCK, TPK, TCK, and TK – and noting that the Cronbach's alpha coefficients were satisfactorily high, composite variables were computed for each construct. Specifically, these composite variables, named correspondingly as TPCK, TPK, TCK, and TK, were calculated as the mean scores of the respective items within each construct.

Subsequent to the calculation of the composite variables, a validation procedure was conducted to ascertain the robustness of these measures. This involved correlating each composite score with its respective indicators. The analysis yielded significantly high correlations, thereby affirming the validity of the composite scores as reliable representations of the underlying constructs. These results substantiate the composite variables' effectiveness in capturing the essence of the TPCK, TPK, TCK, and TK constructs.

The majority of the survey questions were measures of participant confidence related to four TPACK constructs. For each of the survey items (TPCK, TPK, TCK, and TK) we calculated descriptive statistics including means, standard deviations, minimum, and maximum (Table 2).

It is visible, that physics teachers feel more confident in TPK ($TPK_M = 4.79$). This indicates that they feel confident in their ability to use digital technology effectively to engage students and enhance teaching efficiency. However, they exhibit lower and more variable confidence in TCK ($TCK_M = 3.71$), which might suggest areas for additional support in integrating content-specific technology.

For further assessing the reliability of the measurement constructs related to the TPACK framework, in addition to Cronbach's alpha, the Average Variance Extracted (AVE) was calculated. The AVE indicates the level of variance captured by a construct in relation to the variance due to measurement error. Higher AVE values suggest that a greater proportion of the variance in the indicators is explained by the latent construct, reflecting good construct validity (Table 3):

However, the TK construct presents a relatively lower AVE of 56.32%, indicating that a significant portion of the variance may be due to measurement error or that the construct may not be adequately capturing the underlying concept it intends to represent. This lower percentage signals the need for further investigation to ensure that the construct's validity is robust. As the percentage of variation (AVE) is relatively low for the last construct, exploratory factor analysis was additionally conducted on all variables together, the result of which is as follows (Table 4):

The subsequent exploratory factor analysis provides an opportunity to refine these constructs, particularly addressing the concerns raised by the lower AVE in the Tech construct. The combination of these analyses supports the development of a more accurate and effective measurement tool for assessing TPACK, ultimately benefiting educational practices and teacher development initiatives.

The factor analysis results grouped the variables into four factors, which explain approximately 75% of the total variance.

As a result of the exploratory factor analysis of all variables, 4 factors came out again, although the variables in our study were regrouped as follows: (Table 5).

After this, we discussed new constructs where variables were grouped based on the results of this factor analysis. Specifically, in the first construct, we got a new variable – integrated TPK, all variables combined from the initial two constructs TPCK and TPK, and the last of the initial constructs TK was divided into two parts: simple sTK (TK1-TK5) and complex cTK (TK6-TK11) TK skills. For these new constructs, we again conducted a reliability analysis of the constructs using the "lavaan" package in R.

In this case as well, the correlations of the indicators with the latent variables are high, while the reliability characteristics in this case are as follows (Table 6):

Table 1: Reliability coefficients for technological content knowledge constructs

Construct	Cronbach's alpha (α)
TPCK	0.95
TPK	0.95
TCK	0.95
TK	0.92

TPCK: Technological pedagogical content knowledge, TPK: Technological pedagogical knowledge, TCK: Technological content knowledge, TK: Technological knowledge

Table 2: Descriptive statistics for all items

Composite variables	Mean	SD	n	Minimum	Maximum
TPCK	4.55	0.99164	135	2.00	6.00
TPK	4.79	0.91803	135	2.29	6.00
TCK	3.71	1.45223	135	0.00	6.00
TK	4.70	0.91974	135	1.73	6.00

TPCK: Technological pedagogical content knowledge, TPK: Technological pedagogical knowledge, TCK: Technological content knowledge, TK: Technological knowledge, SD: Standard deviation

Table 3: Average variance extracted

TPCK	TPK	TCK	TK
71.07	73.72	80.14	56.32

TPCK: Technological pedagogical content knowledge, TPK: Technological pedagogical knowledge, TCK: Technological content knowledge, TK: Technological knowledge

Table 4: Exploratory factor analysis

Total variance explained						
Component	**Initial eigenvalues**			**Rotation sums of squared loadings**		
	Total	**Percentage of variance**	**Cumulative (%)**	**Total**	**Percentage of variance**	**Cumulative (%)**
1	17.82	57.48	57.48	8.93	28.79	28.79
2	2.52	8.11	65.59	5.18	16.71	45.50
3	1.54	4.96	70.55	4.53	14.61	60.11
4	1.25	4.03	74.58	4.49	14.47	74.58

Table 5: Rotated component matrix

Items	**Component**			
	iTPK	**TCK**	**sTK**	**cTK**
TPCK1	0.648			
TPCK2	0.453			
TPCK3	0.741			
TPCK4	0.815			
TPCK5	0.799			
TPCK6	0.725			
TPCK7	0.733			
TPCK8	0.667			
TPK1	0.821			
TPK2	0.738			
TPK3	0.688			
TPK4	0.695			
TPK5	0.760			
TPK6	0.686			
TPK7	0.447			
TCK1		0.762		
TCK2		0.652		
TCK3		0.854		
TCK4		0.833		
TCK5		0.823		
TK1				0.712
TK2				0.783
TK3				0.819
TK4				0.798
TK5				0.676
TK6			0.657	
TK7			0.724	
TK8			0.686	
TK9			0.761	
TK10			0.679	
TK11			0.675	

TPCK: Technological pedagogical content knowledge, TPK: Technological pedagogical knowledge, TCK: Technological content knowledge, TK: Technological knowledge, iTPK: Integrated TPK, TCK: Technological content knowledge

At the final stage, we reviewed the new constructs, where the variables were grouped based on the results of the factor analysis. Specifically, in the first construct, all the variables of the initial two constructs (TPCK and TPK) are combined, while the last of the initial constructs are divided into two parts.

Table 6: Reliability characteristics (Cronbach's alpha (α) and average variance extracted)

Reliability characteristics	**iTPK**	**TCK**	**sTK**	**cTK**
Alpha	0.97	0.95	0.88	0.91
Avevar (%)	69.22	80.13	62.30	64.09

iTPK: Integrated technological pedagogical knowledge, TCK: Technological content knowledge

DISCUSSION AND CONCLUSION

The results obtained from the quantitative research comprehensively reflect the self-evaluation data about the technological skills of physics teachers in Georgia. This analysis not only highlights the current state of technological proficiency among educators but also could serve as a foundation for understanding the broader implications of technology integration in physics education.

Based on our results Georgian physics teachers feel more assured in TPK ($TPK_M = 4.79$), indicating their confidence in effectively integrating technology with pedagogical strategies in the learning process. Moreover, the lower confidence is observed for TCK ($TCK_M = 3.71$). This means they may be uncertain about how to apply digital tools or resources in ways that deepen students' understanding of particular topics. This lack of confidence may stem from limited training or experience with integrating technology into subject-specific instruction. Slightly different results were noted for Turkish in-service science teachers (Timur and Taşar, 2011) – they felt more confident in TK ($TK_M = 3.33$), but for TCK was also observed the lowest confidence ($TCK_M = 3.16$). There was also a slight difference in measurement scale for these two studies – in our case measurement tool consisted of six scales, and for the Turkish study – five scales.

Based on our factor analysis results, variables are grouped into 4 factors. Our findings differ from those of other studies: Lee and Tsai (2010) identified five web-specific factors, Pamuk et al. (2015) and Sang et al. (2016) identified seven factors, while Archambault and Barnett (2010) found only three. We found out that TPACK and TPK were effectively merged into a single construct. This indicates that the teachers involved in the study perceive these concepts as conceptually identical. They expressed a belief that managing a technology-equipped classroom effectively would inherently facilitate their ability to adapt content for their students. For instance, they conveyed that if they utilize digital technologies to actively engage students in the learning process, they can effortlessly make the subject matter more interesting and accessible. This insight highlights the interconnectedness of technological and pedagogical skills, suggesting that educators may not distinctly differentiate between the two when applying them in real-world teaching scenarios. However, contrasting results have been documented in the literature, such as in the work of Graham (2009), which suggests that there may be variability in how these constructs are understood and operationalized across different educational contexts.

Regarding the division of the last construct, TK, into two parts, our analysis yielded intriguing results as well. Skills such as saving an image from a website to a computer, finding relevant information online, sending an email with an attachment, and creating presentations or documents with text and images were found to be relatively straightforward for teachers. These tasks represent basic technological competencies that educators appear to have mastered and regularly employ in their teaching practices. However, we observed that more complex tasks, such as independently learning to install new software, recording and editing digital photos and video clips, effectively using various web technologies, and creating their own websites, posed greater challenges. This distinction led us to classify the skills within TK into two categories: Simple sTK (TK1-TK5) and complex cTK (TK6-TK11) TK skills. The new category names are assigned based on the content of these categories. These results obtained in the context of Georgia, are different compared with the other countries (Graham, 2009). This classification not only provides clarity regarding the types of technological skills possessed by physics teachers but also identifies specific areas where additional PD may be necessary. Science teachers may require training and resources in computer technology to enhance their technology-related knowledge (Jang and Tsai, 2013).

This classification is reinforced by the preliminary analysis of the qualitative research data and is supported by a logical rationale. Georgian teachers tend to view the use of technology for various purposes – such as facilitating inquiry-based learning, assisting students in data collection, communicating with students, or conducting effective assessments – as interchangeable. Basic technological skills, including saving images, sending emails, or creating presentations, are often categorized together. In contrast, more complex tasks, such as developing a personal website or independently learning new software, are recognized as challenging and distinct from these main activities.

The identification of simple and complex technological skills within the TK construct underscores the need for targeted training and resources that can bridge the gap between basic competencies and more advanced technological capabilities. By equipping teachers with the tools and knowledge necessary to tackle complex technological tasks, educational institutions can enhance the overall effectiveness of technology integration in the classroom. Furthermore, understanding these skill levels allows for more tailored PD programs that address the specific needs and challenges faced by educators, ultimately leading to improved educational outcomes for students.

Studies suggest that PD programs positively impact teachers' development of TPACK (Guzey and Roehrig, 2009; Graham et al., 2009; Varma et al., 2008) and support successful technology integration into teaching practices (Niess, 2005; Harris and Hofer, 2011; Mishra and Koehler, 2009). Recognizing that technological skills present challenges for teachers in Georgia, particularly in rural and resource-limited areas, suggests an urgent need for new approaches in teacher PD training. One innovative step involves integrating mobile technology, particularly smartphones (González et al., 2015; Carroll and Lincoln, 2020; Kuhn and Vogt, 2022), which are widely accessible to teachers and students. The recent training initiative for physics teachers exemplifies this approach, incorporating two selected mobile applications into a module designed to support and enhance physics education. With smartphones as the primary accessible resource, Georgian schools can leverage these devices to bring interactive and engaging learning experiences directly to the classroom, bridging resource gaps effectively (Mishra and Koehler, 2006).

We recommend utilizing the TPACK model to enhance teachers' technological competencies in the country. We assume that significant changes are needed in university-level pre-service teacher education programs, and in-service teachers should also be equipped with updated TK. It is important to organize training for in-service and pre-service teachers on integrating technology effectively with pedagogy and CK. It is also recommended to develop materials tailored to the Georgian context, focusing on using educational technologies.

As a conclusion, by incorporating the TPACK framework and encouraging collaboration among educators and policymakers, the Georgian educational system can strengthen the integration of technology into effective teaching practices.

LIMITATIONS

The current research has certain limitations that must be acknowledged to contextualize the findings accurately. The significant constraint is related to the participant selection process. Specifically, due to the nature of the study and the logistical challenges involved, the vast majority of physics teachers in Georgia were unable to participate in the quantitative research process. This limitation is particularly noteworthy as it may affect the representativeness of the sample and, consequently, the generalizability of the findings to the broader population of physics educators across the country.

In conclusion, while this research contributes valuable insights into the self-evaluation of the technological skills of physics teachers in Georgia, it is essential to consider these limitations when interpreting the results. Future studies should aim to include a broader range of participants and utilize mixed-methods approaches to capture a more holistic view of technology integration in physics education. Addressing these limitations will enhance the validity of findings and provide a clearer understanding of the landscape of TPACK among physics educators.

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Appendix 1

Technological Pedagogical Content Knowledge (TPACK)

TPCK1. Find and use online animations that effectively demonstrate a specific scientific principle.
TPCK2. Use the Internet to discover common learner misconceptions related to a science topic.
TPCK3. Use digital technologies to facilitate scientific inquiry in the classroom.
TPCK4. Use digital technologies that facilitate topic-specific science activities in the classroom.
TPCK5. Help students use digital technologies to collect scientific data.
TPCK6. Help students use digital technologies to organize and identify patterns in scientific data.
TPCK7. Help students use digital technologies that extend their ability to observe scientific phenomenon.
TPCK8. Help students use digital technologies that allow them to create and/or manipulate models of scientific phenomenon.

Technological Pedagogical Knowledge (TPK)

TPK1. Use digital technologies to improve my teaching productivity.
TPK2. Use digital technologies to improve communication with students.
TPK3. Effectively manage a technology-rich classroom.
TPK4. Use digital technologies to motivate learners.
TPK5. Use digital technologies to improve the presentation of information to learners.
TPK6. Use digital technologies to actively engage students in learning.
TPK7. Use digital technologies to help in assessing student learning.

Technological Content Knowledge (TCK)

TCK1. Use digital technologies that allow scientists to observe things that would otherwise be difficult to observe.
TCK2. Use digital technologies that allow scientists to speed up or slow down the representation of natural events.
TCK3. Use digital technologies that allow scientists to create and manipulate models of scientific phenomenon.
TCK4. Use digital technologies that allow scientists to record data that would otherwise be difficult to gather.
TCK5. Use digital technologies that allow scientists to organize and see patterns in their data that would otherwise be hard to see.

Technological Knowledge (TK)

TK1. Save an image from a website to the hard drive of your computer.
TK2. Search the web to find current information on a topic that you need.
TK3. Send an email with an attachment.
TK4. Create a basic presentation using PowerPoint or a similar program.
TK5. Create a document with text and graphics in a word processing program.
TK6. Learn a new program on your own.
TK7. Install a new program that you would like to use.
TK8. Take and edit a digital photograph.
TK9. Create and edit a video clip.
TK10. Use Web 2.0 technologies (e.g., blogs, social networking, podcasts, etc.).
TK11. Create your own website