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Bridging the gap in technology integration in education: An examination of science teachers' competencies and needs

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ABSTRACT
This study investigates science teachers' perceptions of their level of Technological Pedagogical Content Knowledge (TPACK) and the challenges they face in integrating technology into the classroom. Using a case study approach, data were collected through the TPACK scale and semi-structured interviews with 102 science teachers. The results reveal significant deficiencies in teachers' design and proficiency dimensions of TPACK, which impact on their ability to integrate technology effectively. While basic technologies such as smart boards and presentation software are commonly used, the lack of advanced integration is attributed to insufficient infrastructure, inadequate training and limited discipline-specific materials. In addition, dissatisfaction with professional development programs and low levels of technological literacy among students further hinder technology integration. The findings emphasize the need for tailored, practical training programs and improved infrastructure to address these challenges. It also highlights the importance of incorporating student-centered, technology-enhanced learning strategies to promote effective teaching practices. Curriculum revisions, collaborative training programs, and further research into the pedagogical impact of technology integration are recommended.

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Introduction

In recent years, the impact of educational technologies on teaching processes has increased significantly. This development is not merely confined to the digitization of instructional tools but also necessitates a more effective consideration of the relationship between instruction and technology (Angeli & Valanides, 2009; Dinçer, 2021a; Mishra & Koehler, 2006). When examining the applications of technology in education, two distinct concepts prominently emerge: "technology use in education" and "technology integration in education," which are often used interchangeably.

The term "technology use in education or instruction" refers to the deliberate incorporation of technological tools into the learning process to achieve predetermined learning outcomes. This use is typically limited to providing instructional support. For example, using a projector to deliver a presentation during a lesson exemplifies technology use in instruction (Mishra & Koehler, 2006). While this approach aims to visually support the teacher's presentation, it does not represent the effective integration of technology within the pedagogical or content context (Ertmer & Ottenbreit-Leftwich, 2010; Harris & Hofer, 2011; Hew & Brush, 2007). In essence, technology use in instruction treats technology as a supplementary tool without fundamentally altering instructional strategies or methods.

Technology integration in instruction is used to describe the incorporation of technology into teaching processes in a way that is consistent with the pedagogical objectives of the course or program in question. In other words, integration entails not only the presence of technology in the classroom but also its transformation into an integral component of instructional strategies (Dinçer, 2021a; Dinçer & Çengel-Schoville, 2022). This signifies that technology is not merely a tool but rather a fundamental component of the teaching process (Mishra & Koehler, 2006). Effective technology integration necessitates the restructuring of pedagogical strategies and the integration of content knowledge with technology. To illustrate, a teacher adopting a student-centered approach in a science class may utilize simulations or data collection tools for interactive learning or enrich the learning experience through collaborative digital platforms. Such practices exemplify the integration of technology in instruction (López-Nuñez, Alonso-García, Berral-Ortiz, & Victoria-Maldonado, 2024; Ng & Fergusson, 2019). In conclusion, technology integration in instruction can be defined as the balanced combination of technology, pedagogical knowledge, and content knowledge (Dinçer, 2021b; Harris & Hofer, 2011).

The distinction between technology use and technology integration in education has considerable implications for the efficacy of educational processes. The utilization of technology in an instructional context is frequently confined to particular objectives, such as the conveyance of information or the presentation of data in a visual format (Kay & LeSage, 2009; Wiebe, Slykhuis, & Annetta, 2007). In contrast, technology integration in instruction aims to transform teaching strategies and establish alignment between technology and pedagogical content (Mishra & Koehler, 2006). The utilization of technology in an instructional context is often teacher-centered, with a particular focus on providing support for teaching materials (Ertmer & Ottenbreit-Leftwich, 2010). Conversely, technology integration is student-centered and aims to facilitate active student engagement (López-Nuñez et al., 2024). While technology use in instruction does not typically result in a fundamental alteration of the existing pedagogical structure and does not necessitate a direct connection between technological tools and pedagogical content (Dinçer, 2021a; Harris & Hofer, 2011), the integration of technology requires the redesign of pedagogical processes and the seamless incorporation of technology as an integral component (Angeli & Valanides, 2009; Dinçer & Çengel-Schoville, 2022). Finally, while basic technological knowledge is often sufficient for technology use in instruction, technology integration requires teachers to develop competencies in technology, pedagogy, and content knowledge (Dinçer, 2021b).

A review of the literature reveals that the majority of studies investigating the relationship between technology and instruction focus on the use of technology in education. Conversely, studies pertaining to the integration of technology in instructional settings predominantly emphasize the development of models. Regardless of whether the studies examine the use of technology or its integration into the learning process, the majority of them identify several limitations. The most commonly cited challenges are related to hardware and infrastructure constraints, as well as the competencies of teachers and students. In order to address the challenges associated with technology integration in instruction, a number of models have been proposed. Among these, the Technological Pedagogical Content Knowledge (TPACK) framework, developed by Mishra and Koehler (2006), has gained prominence in the academic literature. The TPACK model is designed to facilitate a productive equilibrium among technology, pedagogical expertise, and content knowledge, integrating these three elements to develop effective pedagogical strategies (Angeli & Valanides, 2013). However, translating this model into classroom practice necessitates not only theoretical understanding but also practical training and hands-on experience (Čipková, Karolčík, Fuchs, & Vaněková, 2024).

The integration of technology into instruction has become particularly significant in the teaching of science, where it facilitates students' understanding of scientific knowledge, visualizes abstract concepts, and supports the development of scientific skills (Jonassen, 1995; Linn, Clark, & Slotta, 2003). This highlights the critical role of the TPACK model in effectively addressing these demands. However, when examining the challenges faced by science teachers in the context of

TPACK, it becomes clear that infrastructure deficiencies, inadequate equipment, limited instructional materials, and a lack of pedagogical knowledge stand out as prominent issues (Ertmer & Ottenbreit-Leftwich, 2010; López-Nuñez et al., 2024). Science teachers frequently report access issues to technological tools such as laboratory equipment, simulations, and data collection devices. These deficiencies restrict their pedagogical practices and negatively impact student learning outcomes (Smetana & Bell, 2012; Tondeur, Van Braak, Sang, Voogt, Fisser, & Ottenbreit-Leftwich, 2012). In addition to the commonly cited hardware and infrastructure limitations, curricular constraints and teacher-student competencies pose significant barriers to successful technology integration.

The inadequacy of professional development curriculums with regard to content and methodology serve to compound the difficulties encountered by teachers in the context of technology integration (Čipková et al., 2024; Hew & Brush, 2007). The literature indicates that such syllabus often priorities theoretical knowledge over practical experience (Cheng, Molina, Lin, Liu, & Chang, 2022; Ng & Fergusson, 2019; Sui, Yen, & Chang, 2024). This limitation restricts opportunities for teachers to enhance their TPACK levels, thereby negatively affecting technology integration processes. Furthermore, students' proficiency in technology usage is of paramount importance in the context of instructional processes. Teachers' efforts to integrate technology are frequently constrained by students' inadequate levels of technological literacy. These shortcomings impede the attainment of pedagogical objectives during instructional processes (Dinçer, 2017a; Koehler & Mishra, 2009; López-Nuñez et al., 2024).

Considering the issues outlined above, assessing the TPACK levels of science teachers, understanding how they use technology in their lessons, and identifying the challenges they face in these processes are expected to provide valuable insights for educational policies and professional development programs. Building on this premise, the present study aims to assess the TPACK perceptions of science teachers, examine their practices regarding technology use and integration in instruction, identify the challenges they encounter, and evaluate the quality of the training they have received. In line with this objective, the following research questions are addressed:

1) What are the TPACK perception levels of science teachers?

2) What are the practices of science teachers regarding the use and integration of technology in education or instruction?

3) What are the primary challenges science teachers face when using or integrating technology in education or instruction?

4) What is the level and quality of the training science teachers have received related to educational or instructional technologies?

Methods

The aim of this study was to examine the contexts in which science teachers use and integrate technology in the classroom and the challenges they encounter in these contexts. To achieve this aim, the research method was designed as a case study. Both quantitative and qualitative data were analyzed in the study. To collect these data, a brief interview was conducted with the teachers, during which the purpose of the study was explained. The common and distinct aspects of these two concepts were clarified by sharing documents with the participants about the use of technology in teaching and technology integration in teaching. Subsequently, the Technological Pedagogical Content Knowledge Scale (TPACKS) (Yurdakul Kabakçı et al., 2012) was administered to the participants, followed by interviews with the participants that were recorded. The raw data from the interview recordings were transcribed, and the findings of the study were generated by analyzing these transcriptions in detail.

Participants

Before the study commenced, science teachers from 29 randomly selected secondary schools were briefed on the research process, and teachers who volunteered to participate in the study were identified. The participants of the study included 102 science teachers, with professional experience ranging from 9 to 18 years, consisting of 42 male and 60 female participants.

Data Collection Tools

In case studies, the diversification of data is of paramount importance (Barcın Kara & Kuşdemir Kayıran, 2024). In accordance with the aforementioned, the data collection instruments utilized in this investigation included interview recordings and the Technological Pedagogical Content Knowledge Scale (TPACKS), developed by Yurdakul Kabakçı et al. (2012). During the interviews, the participants were asked the following questions:

1) Would you rate the frequency of your technology use in instruction on a scale from 1 to 5? (1 = Never, 2 = Rarely, 3 = Occasionally, 4 = Often, 5 = Very Often)
2) Would you rate your level of technology integration in instruction on a scale from 1 to 5? (1 = Never, 2 = Rarely, 3 = Occasionally, 4 = Often, 5 = Very Often)
3) Would you say which technologies you utilize in your lessons?
4) Would you describe the tools you utilize to integrate technology into instruction?
5) Would you indicate the reasons for your inability to utilize technology in your lessons or for your failure to fully integrate technology into your instructional practice?
6) Have you received any in-service training on technology use or integration in instruction during your professional career? If so, please provide your views on the content of such training.
7) During your undergraduate education, did you receive any training on technology use or integration in instruction? If so, please provide your views on the content of such training.

The TPACKS is a five-point Likert scale (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree) developed by Yurdakul Kabakçı et al. (2012). The scale comprises 33 items and exhibits a Cronbach's alpha reliability coefficient of 0.95, indicating a high level of internal consistency. The scale comprises four factors. The four factors are as follows: Design (α=0.92), Exertion (α=0.91), Ethics (α=0.86), and Proficiency (α=0.85). The maximum score that can be attained on the scale is 165.00, while the minimum score is 33.00. The participants were divided into three categories based on their scores on the scale: low (below 95.00), intermediate (between 96.00 and 130.00), and high (131.00 or above). For the sub-factors of the scale, the levels were determined as follows: for Design factor, participants scoring below 28.00 were classified as low level, those scoring between 29.00 and 40.00 as intermediate level, and those scoring 41.00 or above as high level. For Exertion factor, participants scoring below 35.00 were classified as low level, those scoring between 36.00 and 46.00 as intermediate level, and those scoring 47.00 or above as high level. For Ethics factor, participants scoring below 17.00 were classified as low level, those scoring between 18.00 and 24.00 as intermediate level, and those scoring 25.00 or above as high level. And last factor which is Proficiency factor, participants scoring below 14.00 were classified as low level, those scoring between 15.00 and 19.00 as intermediate level, and those scoring 20.00 or above as high level. To ensure the validity and reliability of the collected data, the scale's reliability was recalculated by the researcher. The analysis yielded a Cronbach's Alpha coefficient of 0.87, confirming the scale's reliability for this study.

Data Analysis

Since the research involved multiple types of data, both qualitative and quantitative data analyses were conducted. Means, standard deviations, and frequency distributions were calculated for each sub-dimension and the overall TPACKS score, and participants were categorized into low, intermediate, and high levels based on predetermined thresholds for total and sub-dimension scores.

A frequency analysis was employed to assess the self-reported frequency of technology utilization and integration, with participants rating their usage on a scale from 1 to 5.

The qualitative data were derived from semi-structured interviews. The audio recordings of the interviews were transcribed in their entirety and subjected to thematic content analysis. Initial open coding was conducted to identify recurring themes and concepts. Codes were grouped into categories that aligned with the study's research questions, focusing on the following categories; types of technologies used or integrated in lessons; barriers to technology use or integration; training experiences and evaluations.

To ensure consistency in qualitative analysis, another researcher independently reviewed the coding framework. Any discrepancies were resolved through discussion, resulting in an inter-rater agreement of 83.00%.

Finally, the study employed a convergent design, in which quantitative and qualitative findings were analyzed independently and then integrated to provide a comprehensive understanding. The quantitative results from the TPACK scale were used to identify patterns, which were further explored through the qualitative insights from interviews.

Results

The results obtained from the TPACKS administered to the participants to measure science teachers' perceptions of their TPACK knowledge levels are presented in Table 1. Upon examining Table 1, it was determined that 60.78% (*n*=62) of the participants indicated low-level perceptions of the Design factor, 22.50% (*n*=23) reported intermediate-level perceptions, and 16.67% (*n*=17) reported high-level perceptions. It was established that 71.57% (*n*=73) of the participants reported low-level perceptions of the exertion factor, 10.78% (*n*=11) indicated intermediate -level perceptions, and 17.65% (*n*=18) indicated high-level perceptions. Furthermore, 25.49% (*n*=26) of the participants indicated low-level perceptions of the Ethics factor, 31.37% (*n*=32) reported intermediate -level perceptions, and 43.14% (*n*=44) reported high-level perceptions. It was determined that 48.04% (*n*=49) of the participants reported low-level perceptions of the Proficiency factor, 39.22% (*n*=40) indicated intermediate -level perceptions, and 12.75% (*n*=13) indicated high-level perceptions. When examining the overall TPACK score, it was found that 60.78% (n=62) of the participants indicated low-level perceptions, 24.51% (*n*=25) reported intermediate-level perceptions, and 14.71% (*n*=15) reported high-level perceptions.

Table 1

Participants' perceptions of TPACK knowledge levels

	Low			Intermediate			High			Total		
	n	$\bar{x}$	sd	n	$\bar{x}$	sd	n	$\bar{x}$	sd	n	$\bar{x}$	sd
Design	62	19,87	4,11	23	33,09	3,20	17	44,29	4,10	102	26,92	10,25
Exertion	73	23,97	5,22	11	39,28	3,55	18	53,44	3,84	102	30,83	49
Ethics	26	12,62	1,75	32	19,44	1,45	44	27,86	4,84	102	21,33	7,11
Proficiency	49	9,48	2,38	40	16,20	1,62	13	23,46	1,61	102	13,90	5,22
TPACKS	62	74,40	12,39	25	109,04	9,81	15	143,07	8,69	102	92,99	27,82

In order to evaluate the frequency of technology use and integration in teachers' lessons, participants were asked to rate frequency of their technology use on a scale from 1 to 5; and the findings are presented in Table 2. The results indicate that, with regard to the frequency of technology use in lessons, 5.80% (*n*=6) of the participants reported that they almost never use technology, while 38.20% (*n*=39) reported that they rarely used it. 42.20% (*n*=43) of respondents indicated that they employed technology sometimes, 11.80% (*n*=12) reported often use, and 2.00% (*n*=2) stated that they utilized technology very often. In terms of the frequency of technology integration into lessons, 64.70%

(n=66) of the participants indicated that they almost never integrated technology, while 24.50% (*n*=25) stated that they rarely did so. A further 7.80% (*n*=8) of participants indicated that they occasionally integrated technology into their lessons, while 2.00% (n=2) stated that they often did so, and 1.00% (n=1) indicated that they very often integrated technology.

Table 2

Participants' use of technology and technology integration in their lessons

		almost never	rarely	sometimes	often	very often
Technology Use	n	6	39	43	12	2
	%	5,80	38,20	42,20	11,80	2,00
Technology integration	n	66	25	8	2	1
	%	64,70	24,50	7,80	2,00	1,00

Participants were asked about the types of technologies they use in their lessons, and their responses were coded and categorized. The coding results revealed that participants frequently used presentation devices and software (*f*=96), smartboards (*f*=82), interactive videos (*f*=56), instructional software (*f*=41), experiment kits (*f*=33), simulations (*f*=29), and virtual reality applications (*f*=2) in their lessons. A similar question was asked regarding technology integration, and the coding results revealed that participants frequently used presentation devices and software (*f*=20), smartboards (*f*=12), LMS (*f*=12), and experiment kits (*f*=10).

Participants were queried regarding the underlying reasons for their inability to utilize instructional technologies or to achieve comprehensive technology integration in their lessons. The responses obtained from the interviews were subjected to coding and grouped according to similarity. The coding revealed that the majority of participants identified hardware and infrastructure deficiencies (*n*=94) as the primary reason. Other significant factors included teacher competency (*f*=70), student competency (*f*=68), the incompatibility of the curriculum (*f*=64), and a lack of sufficient content (*f*=42).

The participants were queried as to whether they had undergone training in the utilization of technology or the integration of technology into the instructional process during the course of their professional careers. The results indicated that the vast majority of participants (*n*=99) had attended multiple in-service training sessions on technology use or integration. Upon inquiry regarding their satisfaction with the aforementioned training sessions, the majority of participants (*n*=74) indicated a lack of satisfaction, while a minority (*n*=13) expressed satisfaction. The participants were subsequently queried as to the underlying causes of their discontent with the aforementioned training sessions. The responses indicated that the principal reasons were the unsuitable timing of the sessions (*n*=53), the absence of direct relevance to their teaching subjects (*n*=47), the excessively theoretical nature of the training (*n*=21), and the obligatory nature of the sessions (*n*=3).

The final question posed to participants was whether they had received any course on the utilization or integration of technology in the context of their teacher education. It was determined that 10.78% (*n*=11) of the participants indicated that they had not received such course, 15.69% (*n*=16) reported that they did not recall receiving it, and 75.53% (*n*=75) indicated that they had indeed participated in a course. A total of 75 participants who had received course were invited to indicate their levels of satisfaction with the course they had attended. Among the participants, 65.34% (*n*=49) indicated a lack of satisfaction, 21.33% (*n*=16) reported satisfaction, and 13.33% (*n*=10) did not provide a response. When participants who expressed dissatisfaction (*n*=49) were asked to elaborate on the reasons for their dissatisfaction, the most commonly cited issues were the theoretical nature of the lessons (*n*=31), the lack of content specifically tailored to their subject areas (*n*=26), the inadequacy of the instructors (*n*=21), insufficient lesson duration (n=9), and the low level of students' preparedness (n=3).

Discussion

The literature suggests that participants often exhibit a tendency to present themselves more favorably when responding to self-efficacy measures (Dinçer, 2018; 2019a; Kruger & Dunning, 1999; Rosenman, Tennekoon, & Hill, 2011). This tendency is associated with participants’ behavior of giving high scores to avoid being perceived as “inadequate”. However, in this study, an examination of participants' TPACK perception levels revealed that, except for the Ethics sub-factor, they rated their TPACK levels as low. The participants' acknowledgement of low TPACK levels may be indicative of their willingness to concede the difficulties they encounter in effectively utilizing or integrating technology in an educational context. This result is consistent with previous studies in the literature that have emphasized the positive impact of teachers' openness about their deficiencies regarding technology and their awareness of these issues (Chai, Koh, & Tsai, 2010; Harris & Hofer, 2011; Kramarski & Michalsky, 2015). Nevertheless, the participants' low performance in the Exertion factor indicates that their positive attitudes are not supported by sufficient effort to integrate technology.

The result that the majority of participants reported exerting minimal effort towards achieving technology integration renders this result particularly noteworthy. This may indicate that, despite their awareness, teachers' lack of sufficient infrastructure and motivation leads to a lack of effort in the technology integration process. Previous studies have indicated that this lack of effort highlights the necessity for comprehensive professional development programs designed to enhance technological pedagogical knowledge levels (Čipková et al., 2024; Ng & Fergusson, 2019). The explicit acknowledgement of these deficiencies by the participants represents a valuable starting point for the development of future instructional programs. As previously observed in similar studies (Angeli & Valanides, 2013; Chai et al., 2010; Tondeur et al., 2012), increasing awareness is considered a crucial instrument for overcoming such challenges and fostering greater effort towards technology integration. This further supports the view that awareness-raising initiatives can make a significant contribution to addressing these issues.

The results of this study regarding science teachers' perceptions of their TPACK levels indicate that inadequacies in technology integration are significant challenges at both perceptual and skill levels. Participants’ low averages in the Design and Proficiency sub-factors suggest clear deficiencies in their ability to effectively design instruction utilizing technology. The existing literature highlights that successful technology integration in instruction relies on teachers’ ability to combine pedagogical and technological knowledge with effective design skills (Angeli & Valanides, 2013; Harris & Hofer, 2011; Mishra & Koehler, 2006). In this context, teachers’ low design skills and self-efficacy perceptions appear to be key factors limiting the effective application of technology use and integration in classrooms. Specifically, participants' low perception levels in the Design dimension indicate a significant lack in adapting instructional materials and processes to technology. Similarly, low scores in the Proficiency dimension reveal that teachers struggle to improve their own knowledge and skills, presenting a fundamental barrier to effective technology integration. Harris and Hofer (2011) emphasize that effective technology integration depends on the ability to blend pedagogical and content knowledge with technology, and such deficiencies hinder this process. A study by Wachira and Keengwe (2011) further highlights similar challenges faced by mathematics teachers, particularly infrastructure and professional support shortages, which negatively affect teachers' perceptions of their own competencies in classroom technology integration.

An examination of the findings regarding participants' use of technology in instruction shows that teachers seldom incorporate technology into their teaching practices. This conclusion is supported by their responses in the Proficiency sub-factor of the TPACKS and their frequent mention of tools like presentation software and smartboards when asked about the technologies they use in instruction. Using technology effectively and integrating it pedagogically is closely tied to teachers' self-efficacy perceptions. Harris and Hofer (2011) emphasize that teachers' success in pedagogical strategies depends on their self-efficacy levels. Mishra and Koehler's (2006) TPACK Model demonstrates that effective integration requires a balance of pedagogical, technological, and content knowledge.

Similarly, Angeli and Valanides (2013) argue that strengthening self-efficacy perceptions positively impacts classroom technology integration.

These results highlight the importance of supportive training programs aimed at enhancing teachers' self-efficacy. It is unlikely for a teacher who perceives themselves as inadequate to frequently use technology in their teaching. Additionally, while basic tools like presentations remain foundational in instructional technology, they are no longer seen as innovations but rather as standard instructional materials in a rapidly advancing world (Ertmer & Ottenbreit-Leftwich, 2010; Ng & Fergusson, 2019). Considering that the use of technology in education is a common practice in developed countries, where research often focuses on technology integration rather than basic use, the limited integration among participants is attributed to their low TPACK perception levels and, consequently, their low knowledge levels. Furthermore, technology integration is inherently a more complex process than basic technology use. For instance, Ertmer and Ottenbreit-Leftwich (2010) emphasize that integration is not merely about using technology but requires pedagogical adaptation, further validating this relationship.

A review of the literature reveals a substantial body of research focused on teachers' ability to use and integrate technology in instruction. Many of these studies highlight teachers' inadequacies in this area (Dinçer, 2018; 2019b). However, identifying the root causes of these inadequacies is crucial for proposing effective solutions. Similar to previous studies (Akram, Abdelrady, Al-Adwan, & Ramzan, 2022; Gesta, Lozano, & Patac, 2023), this study also found that the primary limitation hindering teachers from using technology or achieving full technology integration in instruction is the lack of hardware and infrastructure. This limitation is identified as a significant barrier in nearly every study, either directly or indirectly related to the use of technology in education. For example, the absence of essential technological devices, lack of internet connectivity, or slow internet speeds have been identified as factors that impede the learning processes of both teachers and students (Kay & LeSage, 2009; Lucas, 2020). Moreover, the difficulties associated with hardware and infrastructures extend beyond the mere availability of physical resources to encompass concerns pertaining to the upkeep and modernization of these technologies. This has been underscored in prior research (Hew & Brush, 2007; Li, 2023), thereby reinforcing the conclusions of this study.

The results of the study indicate that the reasons teachers struggle to use or integrate technology in instruction are not limited to inadequate physical infrastructure but also include a mismatch resulting from the lack of appropriate technology-based instructional materials. As emphasized in the literature, technology integration is not merely contingent on the physical presence of devices; it is directly related to the availability of pedagogically adapted content and materials (İnan & Lowther, 2010). This highlights the necessity for technology to be developed not merely as a tool, but as a means of achieving educational objectives (Joshi, 2022; Lim et al., 2023; West & Malatji, 2021).

In previous studies, teacher competency has received relatively less emphasis; however, in this study, it emerged as a significant factor in technology use and integration. Participants identified teacher competency as the second most common reason for their inability to use or integrate technology in instruction, which has been interpreted as being closely related to their TPACKS scores. The participants' self-reported low TPACK levels, combined with their acknowledgment of teacher competency as a limitation, suggest that teacher competencies are insufficient for effectively using and integrating technology into instruction. Teacher competencies regarding TPACK have been widely discussed in the literature (Čipková et al., 2024; Kadıoğlu-Akbulut, Çetin-Dindar, Acar-Şeşen, & Küçük, 2023; Ng & Fergusson, 2019; Sui et al., 2024). However, apart from a few studies, there has been limited focus on understanding the underlying reasons for low teacher competencies (Hew & Brush, 2007; Kadıoğlu-Akbulut et al., 2023; Singerin, 2022). The findings from the interviews suggest that the low competency levels of teachers are associated with the quality of the training they have received. This connection highlights the critical need for more effective and tailored training programs to enhance teachers' competencies in technology use and integration.

Despite the fact that the majority of participants reported having received training on technology use and integration during their teacher education or professional careers, their dissatisfaction with these training programs has been identified as a primary reason for their insufficient competency levels (Čipková et al., 2024; Dinçer, 2019b; Kadıoğlu-Akbulut et al., 2023). A review of the relevant literature reveals that such training programs are often delivered with generic content applicable to all fields, rather than being tailored to specific disciplines (Dinçer & Çengel-Schoville, 2022; Harris & Hofer, 2011). This approach is at odds with the principles of the TPACK model, which underscores the necessity of integrating content knowledge (C) with technological and pedagogical knowledge (TP) to ensure comprehensive success (Angeli & Valanides, 2009; Mishra & Koehler, 2006). Regardless of a teacher's proficiency in utilizing a specific tool, the effective application of such tools within their subject area necessitates the acquisition of specialized knowledge and skills (Shulman, 1986; 1987). To develop these competencies, teacher education and in-service training should move away from generic approaches and towards discipline-specific training (Čipková et al., 2024; Darling-Hammond, 2017; Darling-Hammond et al., 2017; Ng & Fergusson, 2019). Moreover, such programs should not be obligatory or excessively theoretical; rather, they should inspire teachers by integrating practical and hands-on elements (Guskey, 2002). Participants' evaluations of the training they received during their teacher education highlight the importance of trainers being subject matter experts. However, the concept of a subject matter expert in the context of TPACK is not straightforward. For instance, an educator specializing in science teaching may not necessarily be an expert in the use of technology for teaching science. In this regard, it is suggested that such courses be co-taught by both educators with expertise in technology and those specializing in the specific subject area. This collaborative approach would facilitate the delivery of up-to-date tools and methods in alignment with pedagogical practices, making the training more effective and relevant.

Another notable reason why teachers struggle to use or integrate technology in instruction is the competency level of students. This limitation, which has been largely overlooked in previous research, is considered a significant finding. While the teacher's competency in utilizing relevant technology is crucial, it is equally important for students to possess adequate knowledge and skills, as they are the ultimate users of these technologies (Angeli, 2005; Astuti, Arifin, Mutohhari, & Nurtanto, 2021; Dinçer, 2017a; López-Nuñez et al., 2024). A review of the literature reveals that studies examining students' literacy in instructional technologies, particularly computers, have consistently identified low levels of competency among students (Dinçer, 2017a, 2017b; Romanchuk, 2021; Sulistiyarini & Sabirin, 2020). These findings are analogous to those observed among teachers and understood to pose a significant barrier to the successful use and integration of technology in education.

It has been concluded that another factor contributing to the inability to use or integrate technology in instruction is the inadequacy of curricula and the lack of sufficient content. When designing instruction, attention must be paid to all elements of the curriculum. Specifically, using or developing materials solely as tools contradicts fundamental instructional principles. Failing to directly incorporate tools into instruction and provide content is considered a significant barrier.

The research findings reveal that one of the reasons for the inability to use or integrate technology in instruction is the inadequacy of curricula and the lack of sufficient instructional content. In the instructional design process, it is essential to move beyond tool-based approaches and meaningfully integrate these tools into pedagogical and content contexts. As Mishra and Koehler's (2006) TPACK framework suggests, technology should not be treated merely as a tool but as a component that combines content and pedagogy. For instance, Ng and Fergusson (2019) highlight that tailoring such approaches to specific disciplines can yield more effective outcomes for both teachers and students. Similarly, Hew and Brush (2007) emphasize that technological materials in curricula often fail to make a direct contribution to the instructional process, further corroborating these findings. In science education, in particular, materials should not merely function as tools for delivering information but should also serve as resources that facilitate conceptual understanding (López-Nuñez et al., 2024). This shift in material design and application is critical for enhancing the effectiveness of technology integration in education.

It is also crucial to emphasize that curricula should not merely focus on the utilization of technology; rather, they should assume an integrative role within a pedagogical context. The incorporation of technology-enhanced self-regulated learning strategies into the material development process has been demonstrated to have a beneficial impact on learning outcomes for both teachers and students (Sui et al., 2024). However, it has been observed that in the majority of existing curricula, the pedagogical context of materials is frequently disregarded, which constrains the potential of technological tools in the instructional process.

Conclusion

This study comprehensively examined science teachers' TPACK perception levels, their use and integration of technology in lessons, and the challenges they encounter in these processes. The findings revealed that teachers generally have low TPACK perception levels, with significant deficiencies, particularly in the Design and Proficiency sub-dimensions. This indicates that teachers struggle to effectively integrate pedagogical and technological knowledge into classroom practices.

The preference of teachers for the use of only presentation devices and smartboards indicates that technology is not being utilized effectively in the context of instruction. This suggests a tendency among teachers to view technology as a mere tool, rather than achieving a high level of integration within the content context. The prevalence of basic-level technology use and the highly limited integration of technology have been linked to the teachers' levels of competency.

The results of the study indicate that deficiencies in infrastructure and hardware are the primary reasons why teachers fail to use or integrate technology effectively. Issues such as internet connectivity problems, the use of outdated devices, and a lack of diverse materials were found to significantly hinder technology integration. Additionally, the lack of discipline-specific material development in curricula emerged as a factor that prevents the effective use of technology within a pedagogical context.

An analysis of the educational backgrounds of teachers revealed that the training they received was largely theoretical, with limited or no discipline-specific content. This indicates an absence of support for the development of teachers' TPACK levels. Furthermore, the study found that students' low levels of technological literacy also constitute a significant barrier to the integration of technology in instruction. In conclusion, the study highlights the necessity for instructional programs that focus on enhancing teachers' TPACK levels through practical, discipline-specific, and motivational training on technology use and integration in education.

Suggestion

Based on the research findings, the following recommendations are put forth to ensure the effective use and integration of technology in education, as well as for future studies.

To effectively use and integrate technology in instruction, it is recommended:

- to improve infrastructure, particularly in terms of internet access, device renewal, and laboratory technologies, considering the challenges teachers face during the technology integration process.
- that teacher education curricula be revised to emphasize instructional technologies within subject-specific training, with the aim of enhancing TPACK levels for science teachers. Moreover, in-service training programs should be designed to be discipline-specific, practical, and motivational. Such programs should be continuous and regularly updated in order to enable teachers to effectively integrate their knowledge of technology, pedagogy, and content.
- that teacher training programs involve collaboration between technology and field experts. It is anticipated that such collaborative endeavours will facilitate the pedagogical integration of technology and the advancement of teachers' subject-specific knowledge and abilities.

- that instructional materials supporting technology integration should be developed to go beyond mere information delivery. These materials should foster active student participation and encourage conceptual understanding.
- that existing curricula should be updated to integrate technology in alignment with pedagogical goals, transforming instructional strategies and supporting technology use through a student-centered approach.
- to develop student-centered instructional programs aimed at enhancing technological literacy, enabling not only teachers but also students to use technology effectively. This will help improve students' skills in working with digital tools.

For future research:

- Comparative studies are recommended to examine the integration of technology across various disciplines to understand how the TPACK model can be applied in different educational settings.
- To evaluate the sustainable impact of professional development programs, long-term longitudinal research is needed to examine how teachers' TPACK levels evolve over time.
- It is recommended to investigate the pedagogical impact of technology integration across different cultural and regional contexts, exploring diverse approaches and barriers to technology use.
- Comparative studies should assess the effects of various professional development programs—such as applied, theoretical, and discipline-specific models—on teachers' TPACK levels.
- Research is needed to explore how students' technological literacy levels influence teachers' efforts in technology integration, identifying strategies to enhance collaboration between students and teachers.
- In specific fields like science education, studies should evaluate the effectiveness of discipline-specific digital tools (e.g., simulations, laboratory applications). These studies should examine how these tools are used by teachers and their impact on students’ learning processes.
- Analyze how teachers with varying TPACK levels differ in their ability to use and integrate technology. Additionally, the impact of these differences on students' academic performance and learning processes should be compared.

Limitations

This study offers valuable insights into the competencies and challenges of science teachers with regard to technology integration, particularly in the context of the Technological Pedagogical Content Knowledge framework. However, it is important to acknowledge certain limitations in order to contextualize the findings and to inform future research.

The study involved the participation of 102 science teachers from 29 middle schools. Although the sample size is sufficient to yield meaningful data, the findings may not be fully generalizable to different educational contexts. It must be acknowledged that the findings may not fully reflect the experiences of teachers in other regions, grade levels, or subject areas.

Quantitative data were collected using self-report scales, which may be subject to social desirability bias. It is possible that participants may have overestimated or underestimated their TPACK competencies or the frequency of technology use and integration.

Although the qualitative data obtained from semi-structured interviews enhanced the findings, the study was based on self-reported perceptions rather than on classroom observations or third-party evaluations. This restricts the capacity to comprehensively elucidate the intricacies of teachers' technology integration practices.

While the study identifies shortcomings in teacher training programs, it does not analyze the specific content or instructional strategies used in these programs. A more detailed analysis of the training materials and methodologies employed could facilitate a more nuanced understanding of the reasons behind the shortcomings of these programs.

The study primarily concentrates on the competencies and experiences of teachers, with a relatively limited examination of student-related factors. Although student technological literacy is referenced, its impact on teachers' integration strategies requires further examination.

It should be noted that the findings are specific to science teachers and may not be applicable to educators in other disciplines. A comparative study across different subject areas could provide a broader perspective on the applicability of the TPACK framework.

It must be acknowledged that the study reflects the technological and pedagogical landscape at a specific point in time. Given the rapid advancements in educational technologies, it is possible that the findings may not fully account for emerging tools and practices.

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The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Data Availability

Data will be made available on request.

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