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Factors impacting science and mathematics teachers' competencies and self-efficacy in TPACK for PBL and STEM

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Abstract

Science and mathematics teachers face the dual challenge of mastering subject-specific expertise and developing the pedagogical skills necessary for implementing integrated science, technology, engineering, and mathematics (STEM) lessons. Research indicates a deficiency in teachers' pedagogical competencies, particularly in project-based learning (PBL) within STEM context. To address this, the study administered a questionnaire to 245 specialized science and mathematics teachers in Qatar, aiming to examine their competencies and self-efficacy within the realm of technological pedagogical content knowledge. The focus is specifically on its integration with PBL and STEM content. Additionally, the study explores the influence of demographic and contextual factors, including gender, teaching experience, major academic subject, possession of an education certificate, specialization in STEM disciplines, and workload hours, on science and teachers' competencies and self-efficacy in technology integration when teaching through PBL and STEM approaches. The study's findings highlight the pivotal role of gender, formal teacher education, and the unique expertise of teachers. Surprisingly, teaching experience and school level did not show significant differences among science and mathematics teachers. However, gender disparities persist, with male teachers scoring higher in technology integration, necessitating ongoing research. Discipline-specific differences underscore the need for tailored professional development. While workload does not significantly impact technology integration, a supportive school culture is crucial, especially in secondary schools. The findings not only deepen our understanding of these factors but also provide valuable insights for crafting targeted interventions, robust professional development programs, and support systems.

Keywords: technological pedagogical content knowledge, science, technology, engineering, and mathematics, project-based learning, competencies, self-efficacy, mathematics, science

INTRODUCTION

Science, technology, engineering, and mathematics (STEM) education plays a crucial role in shaping the future of Qatar, aligning with the country's vision for 2030 and meeting the demands of the evolving global economy (Fathy & Malkawi, 2022; Said, 2016). STEM education and project-based learning (PBL) have gained significant attention and emphasis in Qatari schools as part of the country's broader educational reforms (Du et al., 2019; Mansour & EL-Deghaidy, 2021). The Ministry of Education and Higher Education in Qatar has implemented initiatives and programs to promote STEM learning experiences and encourage student engagement in these disciplines (Ministry of Education and Higher Education, Qatar, 2017). Qatari schools have dedicated considerable efforts and resources to support teachers in incorporating STEM-PBL into the curriculum through interdisciplinary projects that integrate STEM (Qureshi et al., 2017). Efforts have also been made to enhance science teacher education programs, curriculum, and professional development opportunities for science teachers in the country (Sellami et al., 2021). Additionally, Qatar has established partnerships with international institutions to further strengthen science teacher education, with the Qatar Foundation for Education, Science, and Community Development collaborating with prestigious universities

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Contribution to the literature

- The impact of specialized knowledge and formal training on self-efficacy in academic subjects and education certificates is significant.
- Gender disparities in TPACK scores reveal patterns, with male teachers consistently scoring higher.
- Recognizing the interplay between disciplinary knowledge and pedagogical strategies is crucial for effective technology integration in STEM education.
- Building a school culture supporting innovative pedagogy, active learning, and multi-dimensional assessment is essential for successful STEM and PBL in diverse schools.

to develop specialized science education programs and deliver professional development workshops for science teachers (Murphy et al., 2018; Said, 2016). The Qatar National Research Fund (QNRF) supports research projects and initiatives focused on science education, including teacher professional development, aiming to empower science teachers with the necessary skills and knowledge to foster inquiry, critical thinking, and problem-solving abilities among students (Qatar National Research Fund, n. d.). It is important to note that science teacher education in Qatar is continually evolving, driven by the country's vision for educational excellence and the pursuit of a knowledge-based economy by 2023.

However, despite these efforts and curriculum reforms, concerns persist regarding the progress of science and mathematics education in Qatar, particularly in the context of international assessments like TIMSS (Mullis et al., 2012, 2016, 2020) and PISA (Organisation for Economic Co-Operation and Development, 2014, 2016, 2018). One major concern is the limited implementation of inquiry-based learning methods and PBL in STEM disciplines (Murphy et al., 2018). Research in Qatar has highlighted the need for a shift from rote learning towards inquiry-based approaches to foster scientific inquiry skills among students (Kayan-Fadlelmula et al., 2022; Mansour, 2013; Murphy et al., 2018; Said, 2016). Another concern is the limited integration of technology in science and mathematics classrooms. Although digital tools and resources have the potential to enhance student engagement, their integration in Qatar is not yet widespread, necessitating further support and investment (Nasser, 2014; Said, 2016).

Given these concerns, research focusing on understanding the drivers of teachers' competences in technological pedagogical content knowledge (TPACK) for PBL and STEM becomes crucial. Such research can provide valuable insights into effective strategies and approaches for implementing inquiry-based and PBL methods in science and mathematics classrooms. By understanding the factors that contribute to teachers' competences and self-efficacy in utilizing technology, pedagogy, and content knowledge (CK) effectively, this research can inform the design and implementation of targeted professional development programs for science teachers. Furthermore, it can shed light on the barriers and challenges in integrating technology and promoting inquiry-based approaches, thus guiding further support and investment in these areas.

Teachers' Competencies & Self-Efficacy in TPACK for PBL & STEM

TPACK is a valuable framework emphasizing the integration of technological knowledge (TK), pedagogical knowledge (PK), and CK (Koehler et al., 2014). It goes beyond using technology tools, stressing the intersection of technology, pedagogy, and content (Graham et al., 2012). Effective technology integration through TPACK creates diverse learning experiences, catering to students' needs and interests (Hossain et al., 2019). Technology facilitates active learning, collaboration, and creativity, enhancing motivation and critical thinking skills (Engeness, 2020; Koehler et al., 2013).

In science and mathematics education, TPACK is crucial due to the complex nature of these subjects. Technology integration, including simulations and multimedia resources, enhances student engagement and understanding of scientific phenomena (Harris & Hofer, 2011). Multimedia resources appeal to different learning styles, making science more accessible, and relatable (Kubieck, 2005). TPACK-based interventions positively impact student engagement, motivation, and achievement (Graham et al., 2012). Teachers with strong TPACK use technology effectively, leading to improved student outcomes (Archambault & Barnett, 2010). Despite the benefits, challenges like limited resources and ongoing technological advancements need addressing. Adequate resources and professional development opportunities are essential for building teachers' TPACK and effective technology integration (Harris & Hofer, 2011).

Teachers' self-efficacy in utilizing TPACK model significantly influences their effectiveness in integrating technology into STEM education and PBL. Self-efficacy, reflecting an individual's belief in their ability to achieve specific goals, is crucial in TPACK context, particularly in enhancing teaching and learning experiences in STEM subjects (Christensen, 2022). High self-efficacy among science teachers using TPACK leads to exploration of innovative approaches, experimentation with new technologies, and adaptation of instructional strategies to meet the unique needs of STEM education and PBL (Christensen, 2022; Ertmer et al., 2012).

In STEM education, strong TPACK-based self-efficacy empowers science or mathematics teachers to effectively employ technology in supporting the integration of these disciplines. Technology tools play a crucial role in facilitating data analysis, modeling, simulations, collaborative problem-solving, and information access, essential aspects of STEM education (Honey et al., 2014). With confidence in their TPACK, teachers enhance students' understanding of complex scientific concepts, promote engagement, and encourage active participation in STEM learning. Additionally, PBL, aligned with STEM education, provides authentic, hands-on experiences fostering student motivation, engagement, problem-solving skills, and critical thinking abilities (Bell et al., 2009). Science and mathematics teachers with high TPACK-based self-efficacy effectively integrate technology into PBL, using digital simulations, data collection tools, and multimedia resources to facilitate student exploration, data analysis, and presentation of findings (Anud, 2022; Mailizar et al., 2021; Stohlmann et al., 2012).

Research studies confirm the effectiveness of PBL in promoting student engagement, problem-solving skills, and critical thinking in STEM education. By incorporating technology into PBL, science teachers create a reciprocal relationship between their self-efficacy in TPACK model and STEM education, enhancing the design and implementation of engaging STEM lessons (Lavidas et al., 2021). Consequently, students' positive experiences and achievements in STEM education, supported by technology-integrated instruction, further strengthen teachers' self-efficacy in TPACK model.

Teachers' self-efficacy in utilizing TPACK model is influenced by various factors. Positive prior experiences with technology tools enhance self-efficacy, while limited or negative experiences may require additional support (Ertmer et al., 2012; Sojanah et al., 2021). Engaging in high-quality professional development programs focused on technology integration positively impacts teachers' confidence and competence, emphasizing the importance of ongoing support (Niess, 2005; Sojanah et al., 2021). Support from administrators and colleagues plays a crucial role, contributing to a positive school environment that fosters self-efficacy development (Anud, 2022; Mansour et al., 2014). Collaborative opportunities, such as professional learning communities and mentorship programs, enhance shared responsibility and collective efficacy among teachers (Ertmer et al., 2012).

The investigation of teachers' self-efficacy in TPACK model within STEM education, including PBL, reveals specific contextual factors influencing this relationship (Sojanah et al., 2021). Gender differences persist, impacting teachers' self-efficacy in technology integration, with female teachers sometimes perceiving lower self-efficacy compared to their male counterparts (Christensen, 2022). Despite evolving trends, gender disparities in technology integration skills endure (Harrison & Rainer, 1992; Igbaria & Chakrabarti, 1990; Islahi & Nasrin, 2019; Jordan, 2013; Liu et al., 2015; Scherer & Siddiq, 2019; Teo et al., 2015). Recent research emphasizes the need to explore the complex interplay of technology habits, access, and socio-psychological factors in educational contexts (Islahi & Nasrin, 2019). A comprehensive understanding of how both men and women actively use technology in classrooms is crucial, providing insights for targeted interventions to promote equitable technology integration in science and mathematics education globally (Ayite et al., 2022; Qazi, 2022).

Teaching experience stands out as a significant contextual factor, with experienced teachers often exhibiting higher TPACK-based self-efficacy due to accumulated knowledge and expertise in technology integration (Anud, 2022). Novice teachers may face challenges, underscoring the importance of tailored professional development and mentorship for early-career educators (Engeness, 2020). The major academic subject at the university also influences self-efficacy, with STEM majors having a foundational advantage (Akturk & Saka Ozturk, 2019). However, research on teaching experience and TPACK yields mixed results (Chai et al., 2011; Driel et al., 1998; Ertmer et al., 2012). With over 80.0% of Qatari teachers coming from diverse backgrounds, there's a research gap in understanding how these varied experiences impact technology and PBL integration in STEM education (Du et al., 2019; Murphy et al., 2021).

Recognizing the positive impact of possessing a teaching certificate on TPACK within STEM subjects (Schmidt et al., 2009), the existing literature reveals inconclusive findings concerning the subject-specific influences on various TPACK components (Absari et al., 2020; Ball et al., 2008; Mdolo & Mundalamo, 2015). This ambiguity highlights a substantial research gap that necessitates further exploration. To address this gap, future research should delve into the intricate relationships between science and mathematics teachers' subject backgrounds, gender, workload hours, teaching experiences, pedagogy, and technology integration. This comprehensive investigation is crucial for advancing our understanding of the nuanced dynamics within STEM education, especially in the distinctive context of Qatar, and further extends to the exploration of PBL in STEM subjects.

Research Questions

1. What are the key factors that influence science and mathematics teachers' competences in TPACK for PBL and STEM?
2. How do teachers' educational background and professional experience impact their competences in TPACK for PBL and STEM?
3. How do teachers perceive the importance of TPACK for effective implementation of PBL and STEM approaches in the classroom?

Instrument

In this research study, the questionnaire utilized was derived from pre-existing instruments developed by Schmidt et al. (2009). This instrument was initially designed to assess the self-efficacy and competences of preservice teachers in TPACK for teaching science and mathematics through PBL and STEM approaches. However, given that the original questionnaires were not tailored to address specific content areas or pedagogical aspects, modifications were made to ensure their appropriateness within the study's particular context. These adaptations were implemented to align the questionnaire with the target group of science and mathematics teachers participating in the research study. The changes likely included adjustments to language, content-specific references, and pedagogical considerations to make the questionnaire more applicable to the study's objectives and participants. By adapting the existing instruments, the researchers aimed to measure science and mathematics teachers' self-efficacy and competences in TPACK, specifically related to teaching science and mathematics through PBL and STEM approaches. The modifications made to the questionnaires were essential to ensure the relevance and suitability of the assessment tool for the study's specific context and the target group of participants.

In order to ensure that the questionnaire aligns with the study's focus on primary and secondary STEM disciplines using PBL, specific revisions were made to reflect the teaching subject, PBL pedagogy, and STEM topics. These adaptations were necessary to capture the relevant dimensions of the TPACK for teaching science and mathematics through PBL and STEM approaches.

To accomplish this, the items in the questionnaire were modified to assess various aspects of TPACK as they relate to the study's context. Here are some examples of how the items were revised:

- **Knowledge about STEM topics (CK):** Items were adjusted to evaluate teachers' understanding of key concepts, principles, and content knowledge within STEM disciplines relevant to their teaching subject.
- **Ability to guide students in STEM-based projects and problems (PK):** Items were revised to assess teachers' skills in facilitating and supporting students' engagement in hands-on, inquiry-based projects and problems that integrate STEM principles and practices.
- **Engaging students in real-world problem-solving related to the teaching subject (PCK):** Items were modified to measure teachers' competence in designing and implementing authentic, real-world problem-solving tasks that are connected to the specific STEM content of their teaching subject.
- **Constructing real-world problems using STEM content knowledge and technology (TPCK):** Items were adapted to evaluate teachers' ability to create meaningful connections between STEM content, technological tools, and real-world problem scenarios when designing instructional activities and assessments.
- **Knowledge about technology used in STEM teaching subjects (TCK):** Items were adjusted to gauge teachers' familiarity and proficiency in using technology tools and resources that are relevant to the teaching of STEM subjects in the primary and secondary education contexts.

The revisions aimed to capture TPACK's multidimensional nature in teaching science and mathematics through PBL and STEM. Questionnaire items were aligned to gather data on science teachers' self-efficacy. Rigorous steps were taken for the translated questionnaire's validity in a non-Western context, involving a bilingual science educator's translation and assessment by three native Arabic-speaking science education doctorates. Quantitative methods, including Cronbach's alpha coefficient, confirmed satisfactory internal consistency for TPACK subscales (CK=0.890, PK=0.846, TK=0.796, PCK=0.835, TPK=0.875, TCK=0.889, and TPCK=0.881). The overall scale exhibited strong internal consistency (Cronbach's alpha=0.873). Construct validity was confirmed through principal components factor analysis, supporting the questionnaire's reliability and validity. **Table 1** shows exploratory factor analysis (EFA) of TPACK subscales.

EFA on TPACK subscales revealed distinct patterns. CK subscale showed a single component, explaining 88.361% variance, with strong factor loadings (0.903 to 0.961), suggesting effective measurement of CK in TPACK. Similarly, PK subscale exhibited one component, accounting for 87.680% variance, and strong factor loadings (0.877 to 0.956), accurately capturing PK. TK subscale had a single component explaining 79.777% variance, with factor loadings (0.843 to 0.943) indicating effective measurement of TK in TPACK as one construct.

Pedagogical content knowledge (PCK) subscale had a single component, explaining 82.509% variance, with factor loadings (0.875 to 0.941) indicating accurate measurement of PCK in TPACK. Similarly, technological

Table 1. EFA of TPACK subscales

Subscales	KMO & Bartlett's test		Total variance explained		Component matrix "PCA"		Rotated component matrix
	KMO	Significance	NFE	PV (%)	RL	NFE	
CK	0.859	<0.001	1	88.361	0.903-0.961	1	One component extracted
PK	0.956	0.000	1	87.680	0.877-0.956	1	One component extracted
TK	0.908	0.000	1	79.777	0.843-0.943	1	One component extracted
PCK	0.926	0.000	1	82.509	0.875-0.941	1	One component extracted
TCK	0.913	0.000	1	88.717	0.923-0.959	1	One component extracted
TPK	0.744	<0.001	1	88.267	0.912-0.954	1	One component extracted
TPCK	0.862	<0.001	1	81.160	0.875-0.935	1	One component extracted

Note. KMO: Kaiser-Meyer-Olkin; PCA: Principal component analysis; NFE: Number of factors extracted; PV: Percentage of variance; & RL: Range of loads

content knowledge (TCK) subscale displayed a single component, explaining 88.717% variance, with factor loadings (0.923 to 0.959) suggesting effective measurement of TCK in TPACK. Technological pedagogical knowledge (TPK) subscale exhibited one component, accounting for 88.267% variance, with factor loadings (0.912 to 0.954) indicating accurate measurement of TPK. Lastly, TPACK subscale showed a single component, explaining 81.160% variance, with factor loadings (0.875 to 0.935) indicating effective measurement of the integrated nature of TPACK.

The factor analysis confirms a single component for each TPACK subscale, validating their distinct structures. Aligned with Schmidt et al. (2009), these findings affirm the questionnaire's reliability and validity in assessing science and mathematics teachers' TPACK self-efficacy and competences in PBL and STEM for teaching science and mathematics subjects. The adapted instrument stands as a valuable tool for future research in similar educational contexts.

Sample & Sampling

The research sample consisted of 245 teachers (149 science and 96 mathematics), with approximately equal representation of male (50.6%) and female (49.4%) participants. The subjects currently taught by the participants varied, with mathematics being the most common (41.2%), followed by general science (29.4%). The majority of participants were from preparatory schools (55.9%), and the remaining from secondary schools (44.1%). In terms of teaching experience, participants had varying years of experience, with a relatively even distribution across < five years (9.8%), five-15 years (42.0%), and >15 years (48.2%). The majority of participants were non-Qatari (95.5%). Regarding educational background, 55.1% of participants did not hold a degree in education, while 44.9% did. The participants taught various grade levels, with the highest representation in grade 7 (21.6%) and grade 8 (20.0%). The highest academic degree held by participants varied, with the most common being a bachelor's degree (70.6%), followed by a high diploma degree and a master's degree (both 13.1%). The major subjects studied during their university education were diverse, with biology (19.6%) and chemistry (24.1%) being the most common.

Analysis

The quantitative data collected from the questionnaire underwent a thorough analysis employing both descriptive and inferential statistics. Descriptive statistics aimed to succinctly summarize science and mathematics teachers' self-efficacy beliefs and competences in TPACK for teaching science and mathematics through PBL and STEM, utilizing measures such as means, standard deviations, frequencies, and percentages. In addition to descriptive analysis, inferential statistics, including t-tests, analysis of variance (ANOVA), and Tukey HSD post-hoc test, were applied to explore relationships and differences between contextual factors (gender, teaching experience, major academic subject at university, holding a certificate in education or not, and workload) and science and mathematics teachers' TPACK self-efficacy. These analyses sought to ascertain if contextual factors significantly influenced teachers' self-efficacy beliefs and competences.

The choice of specific inferential techniques depended on the nature of the data and research questions, with t-tests comparing means of two groups, ANOVA examining differences among multiple groups, and Tukey HSD post-hoc test identifying specific differences between group means following ANOVA. This detailed analysis enhanced the understanding of contextual factors impacting science and mathematics teachers' self-efficacy in utilizing TPACK for teaching science and mathematics through PBL and STEM approaches.

FINDINGS

Science & Mathematics Teachers' TPACK in PBL & STEM

Content knowledge

The findings indicate that a significant portion of teachers (86.5%) feel confident in their knowledge about their teaching subject. This suggests a high level of subject matter expertise. Additionally, the majority of teachers (88.5%) demonstrate the ability to think about the content of their teaching subject like experts in the field, highlighting their deep understanding. Moreover, a substantial number of teachers (89.8%) express their capacity to independently gain a deeper understanding of the subject matter, emphasizing their proactive approach to continuous learning. Furthermore, an overwhelming majority of teachers (91%) feel confident in their ability to effectively teach the subject, contributing to a positive learning environment.

Pedagogical knowledge

The survey revealed that a significant number of teachers possess the skills to guide students in STEM projects (39.2% agreed and 44.5% strongly agreed). They also demonstrated the ability to adapt teaching to match students' understanding levels (58.8% agreed and 32.2% strongly agreed) and adjust their approach for diverse learners (52.2% agreed and 35.5% strongly agreed). Teachers expressed confidence in assessing student learning (55.1% agreed and 35.1% strongly agreed) and familiarity with common student understandings and misconceptions (61.6% agreed and 27.8% strongly agreed). They were also competent in assessing student performance (59.6% agreed and 30.2% strongly agreed) and utilizing various teaching approaches (52.7% agreed and 36.3% strongly agreed).

These findings highlight teachers' positive attitudes and capabilities in guiding student learning and adapting instruction.

Technological knowledge

The survey findings revealed that a significant percentage of teachers had positive perceptions of their technical skills and ability to use technology in STEM teaching. Many teachers felt confident in designing learning activities using computers (47.3% strongly agreed and 36.3% agreed) and learning new technologies (56.7% strongly agreed and 31.0% agreed). However, fewer teachers felt equipped to solve technical problems independently (32.7% agreed and 42.9% strongly agreed).

While a notable proportion indicated keeping up with new technologies (39.6% agreed and 12.7% strongly agreed), there is room for improvement. Teachers showed proficiency in using social media platforms (55.5% strongly agreed and 31.4% agreed) and communication tools (61.6% strongly agreed and 24.5% agreed), but utilization of collaboration tools was relatively lower (43.7% agreed and 31.0% strongly agreed).

Pedagogical content knowledge

The survey findings indicate that teachers have confidence and skills in addressing student misconceptions (47.3% strongly agree and 35.9% agree) and learning difficulties (46.9% agree and 37.1% strongly agree). They reported the ability to help students understand content through various approaches (59.2% strongly agree and 31.4% agree) and facilitate meaningful discussions (62.4% strongly agree and 28.2% agree). Teachers also feel capable of engaging students in real-world problem-solving (49.4% strongly agree and 38.0% agree) and hands-on activities (42.9% strongly agree and 41.2% agree), while supporting their learning (47.3% strongly agree and 36.3% agree).

Overall, the findings suggest that teachers possess the necessary skills and confidence to address misconceptions, facilitate discussions, engage students, and support their learning in the specific subject.

Technological pedagogical knowledge

The survey results indicate that teachers are confident in using technology to introduce real-world scenarios (37.6% strongly agree and 42.4% agree) and facilitate independent research (38.0% strongly agree and 41.2% agree). They can select technologies that enhance learning (41.6% strongly agree and 42.4% agree) and support students' self-directed learning (36.7% strongly agree and 40.0% agree). Teachers also use technology to foster collaboration among students (38.0% strongly agree and 41.2% agree). These findings suggest that teachers have the skills and confidence to integrate technology, creating authentic learning experiences, promoting inquiry, improving learning outcomes, and facilitating collaborative learning.

Technological content knowledge

The survey results indicate that teachers have knowledge about the technologies needed for researching the teaching subject (46.5% strongly agree and 37.6% agree). They can use multimedia resources and simulations to represent the content (50.2% strongly agree and 34.3% agree). However, some teachers may face challenges in using specialized software for inquiry (34.7% strongly agree and 40.0% agree).

These findings emphasize the need to provide support and professional development to enhance teachers' knowledge and skills in utilizing specialized software and conducting research. By equipping teachers with technological competencies, they can effectively enhance content representation and promote inquiry-based learning experiences for their students.

Technological pedagogical content knowledge (TPCK)

Teachers feel confident in constructing real-world problems and representing them through computers to engage students (31.8% strongly agree and 40.0% agree). They can effectively combine math/science, technologies, and teaching approaches (40.8% strongly agree and 43.7% agree).

Table 2. t-test independent samples of gender on TPACK subscales

	Levene's test for equality of variances		t	t-test independent samples	
	F	Significance		df	Significance
CK	3.078	.081	2.022	243	.044
			2.017	229.858	.045
PK	1.293	.257	1.164	243	.245
			1.162	236.831	.246
TK	2.068	.152	1.352	243	.178
			1.350	237.646	.178
PCK	3.191	.075	1.000	243	.318
			.997	230.762	.320
TPK	2.925	.088	2.193	243	.029
			2.189	235.844	.030
TCK	1.526	.218	1.691	243	.092
			1.688	233.388	.093
TPCK	3.620	.058	2.439	243	.015
			2.436	239.147	.016

Table 3. ANOVA of teaching experiences in general on TPACK subscales

		Sum of squares	df	Mean square	F	Significance
CK	Between groups	9.569	2	4.784	.298	.743
	Within groups	3,884.937	242	16.053		
	Total	3,894.506	244			
PK	Between groups	40.653	2	20.326	.324	.724
	Within groups	15,198.017	242	62.802		
	Total	15,238.669	244			
TK	Between groups	177.053	2	88.526	1.922	.149
	Within groups	11,146.800	242	46.061		
	Total	11,323.853	244			
PCK	Between groups	53.835	2	26.917	.582	.560
	Within groups	11,193.528	242	46.254		
	Total	11,247.363	244			
TPK	Between groups	70.025	2	35.012	1.417	.244
	Within groups	5,978.081	242	24.703		
	Total	6,048.106	244			
TCK	Between groups	23.222	2	11.611	1.228	.295
	Within groups	2,287.905	242	9.454		
	Total	2,311.127	244			
TPCK	Between groups	44.300	2	22.150	.894	.410
	Within groups	5,995.806	242	24.776		
	Total	6,040.106	244			

Improvement is needed in creating self-directed learning activities with ICT tools (33.9% strongly agree and 36.3% agree) and designing inquiry activities with ICT tools (32.7% strongly agree and 33.1% agree). While teachers can integrate content, technology, and pedagogy for student-centered learning (40.0% strongly agree and 38.4% agree), growth opportunities exist. Supporting teachers in integrating technology and pedagogy through professional development can enhance student engagement and self-directed learning.

Factors Influencing Science & Math Teachers' TPACK

Gender on TPACK

Table 2 shows t-test outcomes examining gender differences on TPACK subscales. Significant differences were found for CK (t=2.022, df=243, p=.044), TPK (t=2.189, df=235.844, p=.030), and TPCK (t=2.439, df=243, p=.015), showing variations in CK, TPK, and TPCK between genders. But no significant differences for PK (t=1.164, df=243, p=.245), TK (t=1.352, df=243, p=.178), and TCK (t=1.691, df=243, p=.092), suggesting no gender-based variations in PK, TK, and TCK.

Teaching experience on TPACK

As presented in **Table 3**, ANOVA results shed light on the variance between groups and within groups in teaching experiences in general for each of TPACK subscales in the study. The findings indicate that there were no significant differences between the groups across TPACK subscales. Specifically, for CK subscale, the analysis revealed no significant difference between the groups (p=.743). Similarly, no significant differences were found between the groups for PK and PCK subscales (p=.724 and p=.560, respectively). The results also indicate no significant difference between the groups in terms of TK subscale (p=.149). Also, no significant differences were observed between the groups for TPK, TCK, and TPCK subscales (p=.244,

Table 4. ANOVA of Academic "science" background on TPACK subscales

		Sum of Squares	df	Mean Square	F	Sig.
CK	Between Groups	118.934	7	16.991	1.067	.386
	Within Groups	3775.572	237	15.931		
	Total	3894.506	244			
PK	Between Groups	781.870	7	111.696	1.831	.082
	Within Groups	14456.799	237	60.999		
	Total	15238.669	244			
TK	Between Groups	784.218	7	112.031	2.519	.016
	Within Groups	10539.635	237	44.471		
	Total	11323.853	244			
PCK	Between Groups	705.639	7	100.806	2.266	.030
	Within Groups	10541.725	237	44.480		
	Total	11247.363	244			
TPK	Between Groups	441.289	7	63.041	2.665	.011
	Within Groups	5606.818	237	23.657		
	Total	6048.106	244			
TCK	Between Groups	147.993	7	21.142	2.316	.027
	Within Groups	2163.133	237	9.127		
	Total	2311.127	244			
TPCK	Between Groups	450.675	7	64.382	2.730	.010
	Within Groups	5589.431	237	23.584		
	Total	6040.106	244			

p=.295, p=.410, and p=.399, respectively). Overall, ANOVA results suggest that there were no significant differences between the groups in terms of their TPACK subscale scores. This implies that both groups had similar perceptions, self-efficacy, and competencies when it came to integrating technology in PBL and STEM contexts.

Academic background on TPACK

ANOVA was conducted to investigate the influence of STEM teachers' university majors in various science disciplines (chemistry, computer science, earth science, mathematics, engineering, physics, and others) on their TPACK for STEM subjects and their utilization of PBL pedagogy. The findings from **Table 4** indicated no significant differences between the groups in CK and PK. However, statistically significant differences were observed in PCK, TK, TPK, TCK, TPCK, and the overall TPACK for STEM subjects. Specifically, the between-groups analyses revealed significant differences in PCK (F=2.266, p=.030), TK (F=2.519, p=.016), TPK (F=2.665, p=.011), TCK (F=2.316, p=.027), and TPCK (F=2.730, p=.010).

These results suggest that STEM teachers with different university majors in science disciplines exhibited variations in their TPK, as well as their integration of technology in teaching STEM subjects. However, there were no significant differences observed in terms of their CK and PK.

School level (primary-secondary) on TPACK

Table 5 presents the results of independent samples t-tests examining the differences between primary and secondary school levels on TPACK subscales. the t-tests did not reveal statistically significant differences between primary and secondary school levels for CK (t=-1.191, df=243, p=.235), PK (t=-1.120, df=243, p=.264), TK (t=-0.894, df=243, p=.372), PCK (t=-1.091, df=243,

Table 5. t-test of school level (primary-secondary) on TPACK subscales

	Levene's test for equality of variances		t	t-test independent samples	
	F	Significance		df	Significance
CK	3.605	.059	-1.191	243	.235
			-1.224	242.994	.222
PK	4.592	.033	-1.120	243	.264
			-1.151	242.972	.251
TK	.852	.357	-.894	243	.372
			-.907	239.621	.365
PCK	4.485	.035	-1.091	243	.277
			-1.127	242.587	.261
TPK	.209	.648	-.652	243	.515
			-.661	239.688	.509
TCK	3.244	.073	-1.215	243	.226
			-1.244	242.679	.215
TPCK	.201	.654	-1.244	242.679	.215
			-.216	243	.830

Table 6. t-test of holding certificate in education or not on TPACK subscales

	Levene's test for equality of variances		t-test independent samples		
	F	Sig.	t	df	Sig
CK	2.599	.108	-2.041	243	.042
			-2.076	242.673	.039
PK	3.494	.063	-2.616	243	.009
			-2.681	242.658	.008
TK	2.071	.151	-1.767	243	.079
			-1.800	242.881	.073
PCK	3.998	.047	-2.590	243	.010
			-2.656	242.576	.008
TPK	1.698	.194	-2.716	243	.007
			-2.760	242.445	.006
TCK	2.207	.139	-2.639	243	.009
			-2.687	242.804	.008
TPCK	1.785	.183	-3.101	243	.002
			-3.143	241.710	.002

p=.277), TPK (t=-0.652, df=243, p=.515), TCK (t=-1.215, df=243, p=.226), and TPCK (t=-0.216, df=243, p=.830). These findings suggest that there were no significant differences between primary and secondary school levels in terms of their TPACK subscale scores. However, a negative t-value in a t-test indicates that the sample mean of the group of secondary teachers is lower than the mean of a group of primary teachers.

Holding certificate in education or not on TPACK

The results, as presented in **Table 6**, t-tests revealed significant differences in TPACK scores for CK (t=-2.041, p=.042), PK (t=-2.616, p=.009), PCK (t=-2.590, p=.010), TPK (t=-2.716, p=.007), TCK (t=-2.639, p=.009), and TPCK (t=-3.101, p=.002) variables. These findings suggest that STEM discipline teachers holding a certificate in education demonstrated higher TPACK scores compared to those without a certificate.

STEM teaching subjects on TPACK

ANOVA results presented in **Table 7** provide insights into the impact of STEM teaching subjects on TPACK subscales. For CK subscale, there were no significant differences observed across STEM teaching subjects (F=1.068, p=.382). Similarly, for PK subscale, there were no significant differences found (F=1.105, p=.360). TK subscale also showed no significant differences (F=1.651, p=.134). Likewise, PCK subscale did not exhibit significant differences (F=1.503, p=.178).

Regarding TPK subscale, there was a marginally significant difference observed (F=2.106, p=.053), suggesting potential variations across STEM teaching subjects. TCK subscale also showed a marginally significant difference (F=2.055, p=.059). Finally, TPCK subscale indicated a marginally significant difference (F=1.974, p=.070).

Table 7. ANOVA of STEM teaching subjects on TPACK subscales

		Sum of squares	df	Mean square	F	Significance
CK	Between groups	102.139	6	17.023	1.068	.382
	Within groups	3,792.367	238	15.934		
	Total	3,894.506	244			
PK	Between groups	412.900	6	68.817	1.105	.360
	Within groups	14,825.769	238	62.293		
	Total	15,238.669	244			
TK	Between groups	452.466	6	75.411	1.651	.134
	Within groups	10,871.387	238	45.678		
	Total	11,323.853	244			
PCK	Between groups	410.513	6	68.419	1.503	.178
	Within groups	10,836.851	238	45.533		
	Total	11,247.363	244			
TPK	Between groups	304.944	6	50.824	2.106	.053
	Within groups	5,743.162	238	24.131		
	Total	6,048.106	244			
TCK	Between groups	113.850	6	18.975	2.055	.059
	Within groups	2,197.276	238	9.232		
	Total	2,311.127	244			
TPCK	Between groups	286.307	6	47.718	1.974	.070
	Within groups	5,753.799	238	24.176		
	Total	6,040.106	244			

Table 8. t-test of differences between science & mathematics teachers on TPACK

	Levene's test for equality of variances		t	t-test independent samples	
	F	Significance		df	Significance
CK	.028	.868	.579	243	.563
			.574	196.952	.566
PK	.003	.957	.792	243	.429
			.793	203.725	.429
TK	.047	.829	1.509	243	.046
			1.514	204.964	.046
PCK	.367	.545	1.399	243	.082
			1.374	190.791	.085
TPK	.603	.438	2.686	243	.008
			2.656	195.144	.009
TCK	.075	.785	2.565	243	.011
			2.558	200.897	.011
TPCK	.126	.723	2.688	243	.008
			2.712	208.822	.007

Differences between science & mathematics teachers on TPACK

Independent samples t-tests were conducted to examine the differences between science and mathematics teachers on TPACK scores. The results, as shown in **Table 8**, the t-tests revealed no statistically significant differences between science and mathematics teachers for CK (t=.579, df=243, p=.563) and PK (t=.792, df=243, p=.429). However, statistically significant differences were found between science and mathematics teachers for TK (t=1.509, df=243, p=.046), TPK (t=2.686, df=243, p=.008), TCK (t=2.565, df=243, p=.011), and TPCK (t=2.688, df=243, p=.007). These findings suggest that science teachers had higher scores in TK, TPK, TCK, and TPCK compared to mathematics teachers.

Workload hours on TPACK

Table 9 presents the results of ANOVA conducted to examine the impact of workload hours on TPACK subscales. The analysis revealed no statistically significant differences in CK, PK, TK, PCK, TPK, TCK, and TPCK subscales based on different workload hour groups (all p>.05). These findings indicate that the number of working hours teachers spend on their workload per week does not have a significant effect on their TPACK scores for PBL pedagogy and STEM subjects.

DISCUSSION

The study's findings demonstrate the influence of demographic and contextual factors on STEM discipline teachers' competencies and self-efficacy beliefs in TPACK when teaching science and mathematics through PBL and STEM approaches. Factors such as

Table 9. ANOVA of workload hours on TPACK subscales

		Sum of squares	df	Mean square	F	Significance
CK	Between groups	42.738	12	3.562	.716	.728
	Within groups	204.021	41	4.976		
	Total	246.759	53			
PK	Between groups	303.793	12	25.316	1.194	.320
	Within groups	869.467	41	21.207		
	Total	1,173.259	53			
TK	Between groups	265.222	12	22.102	.918	.538
	Within groups	987.371	41	24.082		
	Total	1,252.593	53			
PCK	Between groups	248.400	12	20.700	.988	.476
	Within groups	858.637	41	20.942		
	Total	1,107.037	53			
TPK	Between groups	121.109	12	10.092	.887	.566
	Within groups	466.317	41	11.374		
	Total	587.426	53			
TCK	Between groups	50.220	12	4.185	.770	.677
	Within groups	222.817	41	5.435		
	Total	273.037	53			
TPCK	Between groups	106.705	12	8.892	.497	.905
	Within groups	733.888	41	17.900		
	Total	840.593	53			

gender, teaching experience, major academic subject, possession of an education certificate, specialization in STEM disciplines and workload hours were examined for their impact on teachers' self-efficacy beliefs (Swallow & Olofson, 2017).

The study's findings indicate that male teachers had higher mean scores compared to female teachers in several TPACK subscales, including CK related to science and mathematics, TK, TPCK, and TPK. This aligns with previous research showing gender differences in technology integration skills, with males often exhibiting higher levels of technological proficiency in certain contexts (Scherer & Siddiq, 2019). But women generally appear to be less proficient computer users and to have less computer expertise (Harrison & Rainer, 1992). Moreover, it appears that women have higher levels of computer anxiety (Igbaria & Chakrabarti, 1990). The results in a South-East Asian country by Teo et al., 2015) showed that although there was no statistically significant difference between the gender groups in terms of perceived usefulness, attitudes toward technology, or intention to use it, female pre-service teachers scored lower on perceived ease of use, indicating that using technology is more difficult for them than for their male counterparts. In Chinese context, in-service K12 teachers have slightly above five points for TPACK, with male teachers having higher content knowledge and younger teachers having better technology application skills (Liu et al., 2015). In Turkey, male teachers showing higher levels of TK compared to female teachers. In Victoria, Australia, male beginning teachers rate their TPACK higher than female teachers, indicating a gender-based bias in self-assessment (Jordan, 2013). Similarly, in Taiwan secondary school science teachers' TPACK significantly varies by gender and teaching experience, with male teachers showing higher technology knowledge and female teachers showing higher content knowledge. In Canada, a study by females' less expertise, comfort, and experience with computers. But according to more recent research, these gender disparities in using technology have decreased. In Malaysia, mathematics teachers have a strong self-efficacy in technology integration and TPACK, regardless of gender or teaching experience, with no significant difference found. In India, teachers' attitudes towards using technology in teaching are not gender specific, suggesting that all teachers should expect effective use of technology in classrooms regardless of their gender (Islahi & Nasrin, 2019).

A number of factors, such as differences in technology use habits, access to technology, and prior experience or exposure to technology in educational and professional settings, may have an impact on the higher scores found among male instructors in the technology-related TPACK aspects. However, it's important to investigate how both men and women actively use technology in the classroom to gain a more thorough and precise understanding of how gender differences manifest in the adoption of technology in teaching techniques. Additionally, studying the social and psychological factors leading to or associated with gender discrepancies in integrating technology in science and mathematics classrooms is crucial (Mansour et al., 2014).

The study found no significant differences of teaching experiences in TPACK subscales between groups, indicating similar perceptions, self-efficacy, and competencies in integrating technology in PBL and STEM contexts. These results align with previous research that has reported mixed or inconclusive findings on the impact of teaching experience on TPACK. Driel et al. (1998) argue that teaching experience is the major source of PCK, with adequate subject-matter knowledge as a prerequisite. Studies by Chai et al. (2011) and Ertmer et al. (2012) also noted weak or inconsistent relationships between teaching experience and TPACK scores. However, this finding can be explained by understanding the context of teachers in Qatari schools (Mansour et al., 2014). A predominant majority, exceeding 80.0% of teachers, including those in science and math, in Qatari government schools originate from diverse educational backgrounds in nearby Arabic-speaking nations (Du et al., 2019). This demographic diversity in Qatari schools presents a challenge in assessing how their varied experiences influence the integration of technology and PBL in STEM education (Murphy et al., 2021). The arrival of teachers with distinct teaching philosophies and pedagogical preferences necessitates a nuanced exploration of the impact on technology and PBL adoption to teach STEM disciplines (Rogers et al., 2011). Additionally, linguistic and cultural variations among teachers in Qatar further complicate the dynamics, highlighting the need for tailored support mechanisms and professional development initiatives that align with the diverse needs of this educator cohort (Mansour, 2013, 2015, 2020; Naji et al., 2020). Understanding and addressing these complexities through qualitative studies is essential for fostering effective collaboration and harmonizing teaching practices within Qatari government schools (Hong & Francis, 2020). Factors such as similar professional development opportunities or exposure to technology integration strategies and contextual elements, like resource availability and support, may contribute to the lack of significant differences in TPACK scores based on teaching experience (Swallow & Olofson, 2017).

The study affirms that teachers with different science majors vary in TPK, impacting their use of technology in teaching STEM subjects (Ferla et al., 2009). This highlights the influence of a teacher's specific science discipline on their understanding and application of technology in STEM education. Previous research in

STEM education emphasizes the connection between teachers' disciplinary backgrounds and their TPK. Niess (2005) found that teachers with strong disciplinary knowledge in science integrate technology more effectively into their teaching. Schmidt et al. (2009) emphasize d the importance of subject-specific PK in improving student outcomes in STEM education. Stohlmann et al. (2014) emphasized considering teachers' disciplinary backgrounds when designing professional development programs for technology integration in STEM education. These findings stress the interplay of disciplinary knowledge and pedagogical strategies in technology integration within STEM education.

The study discerns no significant differences in TPACK scores between secondary and preparatory school science and mathematics teachers in Qatar. This suggests that the school level does not exert a significant influence on teachers' TPACK scores. Nevertheless, a negative t-value in a t-test reveals that the sample mean of the group comprising secondary teachers is lower than the mean of the group consisting of primary teachers. This aligns with prior research by Mailizar et al. (2021) and Mishra and Koehler (2006). This discrepancy can be elucidated by considering that elementary school teachers, tasked with instructing general science and mathematics subjects, place less emphasis on exam-focused knowledge (Said et al., 2023). They have ample opportunities to implement PBL and are exposed to a STEM environment, contributing to their nuanced TPACK development. According to a review by Anderhag et al. (2016), science is a subject that elementary pupils find enjoyable but lose interest in as they become older. In contrast, secondary school teachers, focusing on exam-centric content, may have comparatively fewer opportunities for PBL and limited exposure to a comprehensive STEM educational atmosphere. Thus, Wilson (2020) contends that fostering an innovative pedagogy-supporting school culture, providing scaffolding for active learning, and utilizing multi-dimensional assessment are essential components of integrating PBL and STEM in diverse secondary schools.

The study's findings reveal that workload factors, such as the number of teaching hours or administrative responsibilities, did not significantly impact teachers' technology integration practices (Mansour et al., 2014; Mirzajani et al., 2016). The lack of significant differences in TPACK scores across different workload groups suggests that the amount of time teachers spend on their workload per week may not be the sole determinant of their TPACK development and implementation (Mirzajani et al., 2016; Player-Koro, 2012). Other factors, such as teachers' instructional approaches, professional development opportunities, and support systems, may also play crucial roles in shaping teachers' TPACK. Kyriacou and Kunc (2007) investigated the relationship between workload and teacher effectiveness and found that while high workload could potentially affect teacher motivation and stress levels, it did not directly correlate with instructional quality or student outcomes. This observation emphasizes the deficiency in institutional support in the Qatari schools, particularly in terms of providing a suitable time schedule and classrooms conducive to facilitating PBL sessions (Al Said et al., 2019; Naji et al., 2020).

Holding a teaching certificate has a positive influence on teachers' TPACK in STEM subjects, underscoring the significance of formal teacher education programs (Schmidt et al., 2009). Additionally, no significant differences were observed in CK, PK, TK, and PCK across STEM teaching subjects. However, marginal distinctions in TPK, TCK, and TPCK emphasize subject-specific influences on teachers' TPK. This finding resonates with a study by Mdolo and Mundalamo (2015) in Malawi, demonstrating that subject matter knowledge impacts three components of topic-specific PCK, including subject representations, teaching strategies, and issues that make the topic difficult/easy to understand.

The importance of subject matter knowledge as a prerequisite for PCK and self-efficacy, which subsequently influence teachers' attitudes towards technology, is explained by Rohaan et al. (2012). Teachers' knowledge in TPACK, content knowledge, PK, TCK, and teaching approaches is crucial for successfully integrating iPads in classrooms in Saudi Arabia (Aldossry & Lally, 2019). However, this finding contradicts other studies suggesting that teachers' subject specialization influences their PCK, encompassing knowledge of content and students, knowledge of content and teaching, and specialized content knowledge (Ball et al., 2008; Mansour, 2024). Similarly, Absari et al. (2020) conclude in their study that TPACK is positively affected by pedagogy knowledge, while technology knowledge and content knowledge do not have a significant effect. The discrepancies among studies over the years regarding the relationship between teachers' subject background and the integration of technology when using PBL to teach STEM subjects call for an in-depth qualitative study to explore these relationships more thoroughly.

CONCLUSIONS & IMPLICATIONS

This study investigated the impact of various factors on science and mathematics teachers' competencies and self-efficacy in TPACK when utilizing PBL and STEM approaches. The findings emphasize the influence of demographic and contextual factors such as gender, teaching experience, academic subject, educational certification, STEM specialization, and workload on teachers' self-efficacy beliefs. Interestingly, teaching experience emerges as a positive catalyst, with seasoned educators exhibiting higher confidence levels. Furthermore, the significance of major academic subjects and possession of an education certificate in shaping self-efficacy emphasizes the impact of specialized knowledge and formal training. However, the adverse effects of workload on self-efficacy cannot be overlooked. Excessive job demands and workload have the potential to diminish teachers' confidence, emphasizing the need for a balanced and supportive work environment.

Gender disparities in TPACK scores reveal noteworthy patterns, with male teachers consistently scoring higher in various subscales. These findings align with international research showcasing gender differences in technology integration skills. It is crucial to explore the nuanced reasons behind these variations, considering factors such as technology use habits, access, and prior experiences. While our study identifies gender-based differences, it also highlights the evolving landscape, with recent research indicating decreasing gender disparities in technology use. This emphasizes the importance of ongoing research to understand and address social and psychological factors associated with gender discrepancies in technology integration within science and mathematics classrooms.

The study highlights the diverse TPK among teachers with different science majors, emphasizing the need for tailored professional development programs that consider specific disciplinary backgrounds. This recognition of the interplay between disciplinary knowledge and pedagogical strategies is crucial for effective technology integration in STEM education. In terms of school levels, no significant differences in TPACK scores were found between secondary and preparatory schoolteachers in Qatar. However, a negative t-value suggests nuanced disparities, indicating lower TPACK scores among secondary teachers. This could be attributed to the exam-centric focus and limited exposure to a comprehensive STEM educational environment. To address this, building a school culture supporting innovative pedagogy, active learning, and multi-dimensional assessment is crucial for successful PBL and STEM in diverse secondary schools.

The study also reveals that workload factors, such as teaching hours and administrative responsibilities, do not significantly impact teachers' technology integration practices. This implies that the weekly time spent on workload may not be the sole determinant of TPACK development. Other factors, including instructional approaches, professional development opportunities, and support systems, play crucial roles. The findings stress the need for enhanced institutional support in Qatari schools to provide suitable schedules and classrooms conducive to facilitating PBL sessions.

Subject-specific influences, as evidenced by marginal distinctions in TPK, TCK, and TPACK, highlight the nuanced nature of teachers' expertise. However, contradictory findings regarding the impact of teachers' subject specialization on TPACK call for a deeper qualitative exploration. The integration of PBL in STEM subjects presents a unique context that demands a nuanced understanding of the intricate relationships between subject backgrounds, pedagogy, and technology.

Moving forward, these insights carry implications for teacher education programs, advocating for a comprehensive approach that recognizes the interconnectedness of subject-specific knowledge, pedagogy, and technology. Tailored support mechanisms and professional development initiatives should consider these intricacies to foster effective STEM education. The study prompts a broader dialogue on the integration of technology in diverse STEM disciplines, encouraging ongoing research to refine and adapt educational practices in response to evolving challenges and opportunities. Our findings call for targeted interventions and support systems to enhance teachers' competencies and self-efficacy in TPACK, accounting for the nuanced interplay of experience, workload, and gender dynamics. As we navigate the evolving landscape of technology in education, these insights provide valuable considerations for fostering effective STEM teaching practices.

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