Research in Science Education
https://doi.org/10.1007/s11165-024-10190-5

Fostering Teacher Pedagogical Growth through Entrepreneurial-STEM Literacy Development

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Accepted: 25 July 2024

Abstract
This study centers on designing a targeted professional development (TPD) model to enrich the Entrepreneurial-STEM (E-STEM) literacy of teachers within an integrative conceptual framework. The study is threefold in its purpose: firstly, to investigate the impact of a targeted E-STEM PD on teachers' pedagogical growth (PG), emphasizing familiarity, interest, and confidence in E-STEM literacy principles; secondly, to assess teachers' satisfaction with the TPD content and its delivery format; and thirdly, to explore their perceptions regarding the efficacy of this TPD in empowering them to implement E-STEM learning. A mixed-methods approach was employed through a quasi-experiment involving a single group of 220 teachers from different Communities of Practice (CoPs) across various educational stages. Results revealed a significant positive impact on enhancing the pedagogical principles of E-STEM literacy among teachers, indicating substantial improvements in their three PG components. Participants expressed high satisfaction with the E-SETM TPD content and various delivery formats, underscoring its effectiveness in meeting their needs. This research highlights the strategic importance of teacher professional learning in E-STEM, emphasizing its role in fostering innovation, research, and a skilled workforce.

Keywords Entrepreneurial-STEM learning · Targeted professional development TPD · E-STEM literacy principles · Pedagogical growth PG · Integrated disciplines · Integrated STEM education iSTEMed

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Published online: 22 August 2024

Introduction

As global demands for innovation rise, Entrepreneurial-STEM learning (E-STEM) is gaining worldwide importance for its crucial role in developing students' skills to tackle pressing challenges (Sahin et al., 2024). Concurrently, the UAE has shifted towards a knowledge-based economy, recognizing the importance of acquiring skills for success in a dynamic world (Ibrahim, 2021). This shift involves a strong emphasis on fostering research, promoting innovation, and developing a workforce that is well-equipped with knowledge and skills in various fields, aligning with global trends and technological advancements (Siddiqui & Afzal, 2022). To support this transition, educational practices need to evolve to meet the demands of the changing landscape through emphasizing the development of entrepreneurial mindset within integrated STEM education (iSTEMed). This pedagogical approach integrates knowledge and practices from various disciplines, such as science, technology, engineering, and mathematics (STEM), into a unified project. It goes beyond the confines of these four subjects and is adaptable enough to include additional disciplines like entrepreneurship (E), effectively addressing real-world challenges (Nadelson et al., 2012).

Thus, E-STEM learning plays a crucial role in preparing students for careers as either employees or entrepreneurs by incorporating entrepreneurial principles into non-business disciplines to develop their skills. (Deveci, 2019). Despite the increasing global focus on E-STEM integration from basic to higher education (Saiden, 2017; Eltanahy et al., 2020a; Olawale et al., 2020), challenges in implementation persist, including a lack of interdisciplinary knowledge and insufficient training (Eltanahy et al., 2020b). This highlights the necessity for professional development (PD) programs to promote teachers' pedagogical growth (PG) in integrated disciplines, (Pitiporntapin et al., 2023; Birdthistle at al., 2023), especially in the context of E-STEM (Eltanahy, 2023b; Gardner et al., 2019; Sahin et al.,2024). Research on PDs within iSTEMed has primarily focused on assessing teachers' knowledge, attitudes, and skills that support STEM education and its practices (Weinberg et al., 2021; Hurley et al., 2023). However, a noticeable gap exists in prioritizing PDs that specifically enhance the incorporation of entrepreneurial practices into the STEM disciplines, aiming to improve teachers' PG in E-STEM literacy.

Nurturing Entrepreneurial Teachers

In today's rapidly changing educational landscape, teachers need to adopt entrepreneurial mindsets to effectively lead and innovate. Notably, most teachers are not entrepreneurs and that those accustomed to traditional approaches may face difficulties adapting to interdisciplinary and entrepreneurial teaching.

On one hand, research asserts that teachers possessing entrepreneurial pedagogical knowledge play a crucial role in nurturing students' entrepreneurial competences. Conversely, teachers with lower competencies incorporate fewer activities related to entrepreneurial integration (Joensuu-Salo et al., 2020). Hence, entrepreneurial teaching involves integrating entrepreneurial principles into the learning process to enhance innovation. An entrepreneurial teacher is an educator who adopts this approach through creating opportunities for enhanced creativity and practical skills necessary for entrepreneurship and real-world success (Atlan, 2015). According to Davis (2023), entrepreneurial teachers are proactive and willing to take risks to enhance their teaching practices and school environments. They combine their passions and ideas with practical actions to creating a culture of continuous improvement and innovation.

On the other hand, the main factor that influence the quality of iSTEMed is the competence of teachers, who play a central role in delivering effective STEM teaching (Yoon, 2007; Jituafua, 2020). This emphasises the need to support teachers' PG, viewed as an ongoing process of learning that leads to transformative change. According to Clarke and Hollingsworth (2002), The concept of 'teacher change' is open to various interpretations, linked to unique perspectives on teacher PD. Change can be viewed as personal development, where teachers actively improve their performance. Alternatively, it can be seen as growth or learning, as teachers naturally evolve through professional activities within a community of practice (CoP). These perspectives on change are interconnected rather than mutually exclusive.

Marshall et al. (2017) explained that teachers' PG of competencies, encompassing knowledge (including familiarity with content), skills (such as confidence), and attitudes (such as interest) in the subject matter, play a substantial role in influencing their instruction, consequently, student results. In line with that, Margot and Kettler (2019) asserted that PDs should aim to support teachers for effective E-STEM pedagogy, ensuring successful integration of entrepreneurial principles into the educational framework. Drawing upon the extensive literature regarding the effectiveness of targeted professional development (TPD), it becomes evident that the TPD success hinges on factors like relevance, alignment with goals, active learning, follow-up support, technology integration, collaboration, evaluation, and sustainability (Darling-Hammond, 2017; Kennedy, 2019; Boulay, 2023; Özer & Suna, 2023; Kosanovich & Rodriguez, 2024). Pihie and Bagheri (2011) add that enhancing teachers' entrepreneurial self-efficacy through TPD can lead to more effective teaching practices. Confident teachers are more likely to experiment with new methods and engage students in meaningful learning experiences. Therefore, PD programs designed to develop entrepreneurial competencies are vital for empowering teachers to become agents of change in their educational contexts.

Accordingly, this study adopts the concept of TPD to provide sessions that focus on teachers' needs in the context of E-STEM. TPD, as conceptualized in this research, refers to training sessions specifically designed to address the specific needs, challenges, and goals of a particular group of professionals (E-STEM teachers). The term "targeted" implies that the PD is tailored or focused on a particular set of objectives, skills, and knowledge areas, particularly those related to E-STEM literacy, that are relevant to the E-STEM participants.

Pedagogical Growth Components in Integrated Disciplines

STEM disciplines' teachers play a pivotal role in shaping students' interest in E-STEM careers. Their emphasis is often on teaching STEM knowledge and skills within their comfort zones (Nadelson et al., 2012). Unfortunately, a lack of confidence and interest in STEM instruction can inadvertently limit students' exposure to diverse STEM models (Yoon at al., 2014). An examination of teachers' roles in informal STEM environments reveals deficiencies in elements like vision and self-improvement orientation. Thus, literature has highlighted various PG components essential for effective PDs in integrated disciplines such as familiarity, interest and confidence (Keyhani & Kim, 2020; Pitiporntapin et al., 2023).

Familiarity with subject matter is a key PG component which influences teachers' effectiveness, impacting Pedagogical Content Knowledge (PCK) and fostering confidence in new learning models (Wulff, 2020). Thus, the iSTEMed Framework was introduced to guide successful integration, particularly in PD initiatives. iSTEMed focuses on enhancing teachers PCK, contributing to a comprehensive understanding of integrated disciplines like E-STEM (NRC, 2012). To align with iSTEMed outcomes, Eltanahy et al. (2020a) recommend including teachers with expertise in entrepreneurship, such as business teachers, in E-STEM committees to enhance other teachers' familiarity with entrepreneurial practices, awareness of integration-related changes, and confidence in integrated activities (Gardner et a., 2019; Honey et al., 2014).

The second PG component is the interest, which is crucial for positive attitudes among educators, fostering engagement, creativity, and contributing to iSTEMed progress (Razali et al., 2018). Teachers' methods impact students' interest in iSTEMed, so effective PDs should focus on research-based pedagogies for an engaging learning environment (Hernández-Serrano & Muñoz-Rodríguez, 2020). The literature on integrating entrepreneurial learning into other disciplines has shifted towards enhancing teachers' interest and skills for effective practices by focusing on learnability rather than teachability (Hägg & Gabrielsson, 2019). Recognizing the importance of STEM PG could mediate development in teacher readiness for successful iSTEMed (Margot & Kettler, 2019).

In addition to family and interest, confidence is the third PG component plays a crucial role in teacher self-efficacy to influence student learning in iSTEMed PD. Teachers' comfort and motivation in delivering STEM content are tied to confidence, particularly in unfamiliar subject areas (Chai, 2019). Confident teachers in integrated subjects apply student-centered approaches to inspire curiosity in students (DeCoito & Myszkal, 2018; Woolfolk et al., 2009). If teacher self-efficacy significantly influences behavior, performance, and practices (Davis et al., 2006), high-quality PDs should prioritize enhancing teacher skills, confidence, and interest in iSTEMed (Zhou et al., 2023). In this regard, Yoon (2007) emphasized the pivotal role of teachers' TPD in shaping student outcomes by a multifaceted process. Primarily, by refining teachers' knowledge and skills through training that acts as a catalyst for elevating classroom instruction and advancing students' proficiency levels.

Although, teachers with robust learning capacity show a greater inclination for PDs enhancing teaching practices (Eltanahy, 2018), E-STEM development often lacks insights from research on TPD effectiveness in enhancing iSTEMed pedagogy. Educational efforts should focus on utilizing research opportunities for effective integration of disciplines (Kelley et al., 2020), including E-STEM within the broader STEM landscape.

Conceptual Framework

The conceptual framework of the study integrates two primary models: Pitiporntapin et al.'s (2023) STEM Literacy model and Clarke & Hollingsworth's (2002) Interconnected model of Pedagogical Growth (IMPG), validated by Christian et al. (2012). Figure 1 illustrates the integration between these two models that were employed and refined to guide the design.

In the context of STEM development (Peterson, 2017), educators have proposed various principles of STEM literacy, encompassing STEM awareness, STEM integration, STEM pedagogy, STEM practice, and STEM evaluation (Jackson et al., 2014; Eltanahy et al., 2021). These principles incorporated by Pitiporntapin et al. (2023) into a TPD model,

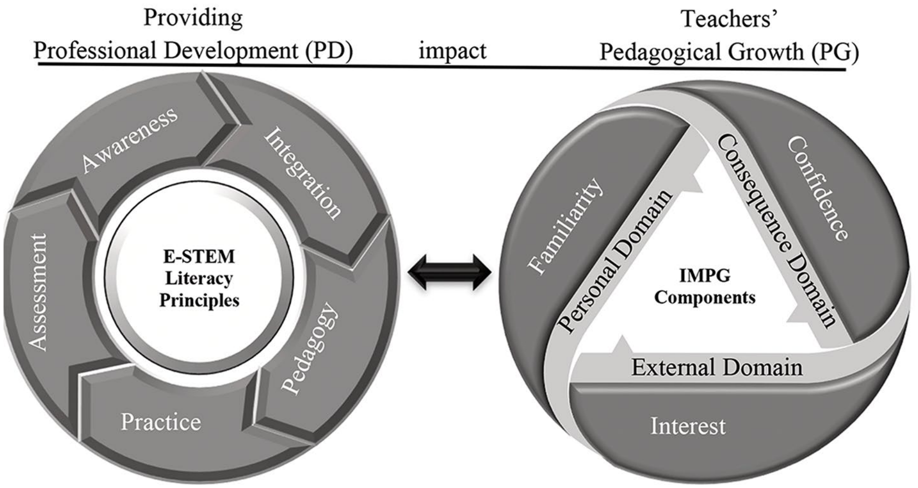

Fig. 1 Conceptual Framework of the Study

resulting in increased STEM literacy scores for participating teachers. Simultaneously, Masunda et al. (2018) highlighted challenges in instilling an entrepreneurial mindset among STEM students, prompting crucial questions on how, what, and when to teach in E-STEM. Addressing these, educators must grapple with overarching questions on why and who is best suited to teach this interdisciplinary model. To guide teachers in finding answers to these questions, this study integrates the TPD model of STEM literacy principles into its design of an E-STEM TPD, aiming to enhance teachers' PG components that are identified in the IMPG model.

E-STEM literacy principles include various dimensions crucial for educational effectiveness. STEM Awareness involves recognizing the interconnected nature of E-STEM disciplines including the rationale behind this integration. STEM Integration emphasizes the level of integration applied and the focus on incorporating E into STEM in each educational stage. STEM Pedagogy involves developing and applying effective teaching methods tailored to E-STEM subjects. STEM Practice emphasizes the integrated activities of STEM in real-world scenarios through hands-on entrepreneurial experiences. STEM Evaluation involves systematically assessing student learning outcomes to develop understanding and instructional effectiveness.

The IMPG model illustrates a non-linear progression across four distinct domains of PG. The practice domain involves professional experimentation through TPDs. The personal domain, encompassing teacher knowledge, beliefs, and attitudes, corresponds to E-STEM familiarity. E-STEM confidence is denoted within the domain of consequence, encompassing salient outcomes, while the external domain, providing stimulus or support, is termed as E-STEM interest. As teachers experience PG, their teaching effectiveness improves and enhances students' content reception (Du et al., 2019) through providing insights into key questions surrounding E-STEM implementation. This conceptual framework guided the TPD sessions, materials and instruments of data collection.

Purpose of the Study

The study aims to examine the impact of the TPD on fostering E-STEM PG of teachers specializing in one of the five E-STEM disciplines (Business, Science, Technology, Engineering, Mathematics), forming the acronym of E-STEM. This investigation includes three key components of PG: familiarity, interest, and confidence, each encompassing five essential E-STEM literacy principles: awareness, integration, pedagogy, practice, and assessment. The research questions guiding the study are as follows:

- Q1: To what extent does targeted professional development TPD impact teachers' pedagogical growth PG to enhance their E-STEM literacy?
- Q2: How satisfied are the teachers with the TPD content and delivery format?
- Q3: What are teachers' perceptions about the effectiveness of TPD on empowering them to implement E-STEM learning?

Methodology

The study employed a mixed methods approach to fulfil the research purpose in four phases (Fig. 2). Quantitative data were collected through a quasi-experimental design with one group using pre-post-test design (Creswell, 2014). Qualitative data were collected through Constructive Grounded Theory (C-GT) via semi-structured interviews. The research methods included a questionnaire and an interview instrument administered to E-STEM teachers.

Participants

The study recruited 220 teachers from various educational stages, including primary education (PE), secondary education (SE), and higher education (HE). Participants were conveniently selected to respond to the pretest after attending the 'STEM Best Practice Summit, frequently held in the UAE to foster STEM reform in the middle east. Then they were

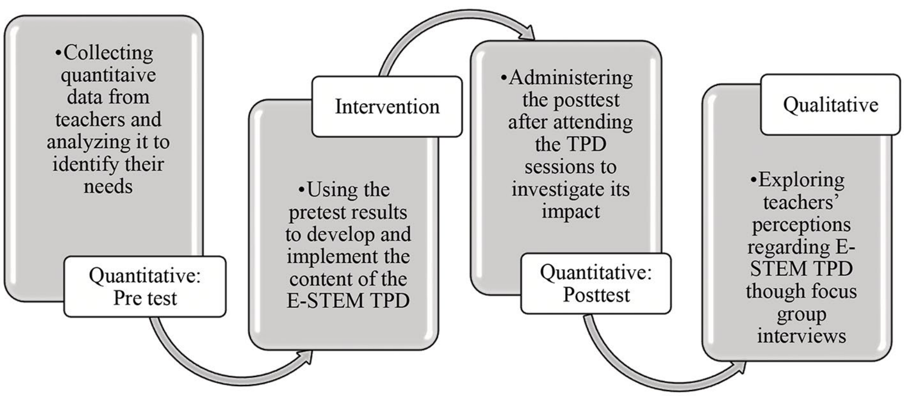

Fig. 2 Data Collection Phases

purposefully recruited again to respond to the post-test after attending the TPD sessions (Creswell, 2014). The purposive sampling strategy ensured a diverse representation of experiences, considering various demographic factors. Regarding the interviews, nine teachers were purposefully recruited using a purposive sampling technique after TPD sessions to explore their perceptions. All ethical issues were carefully addressed to safeguard the participants' rights. Table 1 shows a comprehensive breakdown of the demographic information of the participating teachers.

Research Design

Figure 2 illustrates a four-phase design employed to gather mixed data (qualitative and quantitative) with the aim of preparing and conducting TPD sessions tailored to the requirements of E-STEM teachers. Following this, the impact of these sessions on enhancing their E-STEM literacy was investigated.

Phase 1 Identifying Teachers' E-STEM Pedagogical Needs "Pre-Test"

The data collection started with distributing the pre-test before offering the TPD to teachers gathered at the STEM Summit. The test was distributed electronically during the summit through SurveyMonkey to collect responses on the same day, and in paper form to enhance response rates and prevent delays due to potential technical issues. The aim was to identify teachers' E-STEM pedagogical needs considering PG components to guide the development of subsequent TPD sessions. This involves gauging their familiarity with E-STEM literacy, their interest in participating in TPDs to enhance E-STEM learning, and their current confidence level in implementing E-STEM principles in classrooms.

Phase 2 Intervention-TPD in E-STEM Literacy

All TPD sessions were designed in alignment with the conceptual framework to underscore the importance of structuring TPDs intentionally. The goal was to foster a CoP where teachers collaboratively develop expertise in specific PCK related to E-STEM (Asaoka, 2021), ultimately enhancing learning outcomes. These sessions aimed to boost teachers' familiarity, interest, and confidence in E-STEM literacy.

- **TPD Content & Duration**: The study conducted 50-hour TPD spread over 16 months, targeting five cohorts of teachers. Each cohort, comprising 40–50 teachers, attended five sessions to enhance their E-STEM literacy (Table 2). The TPD content was informed by

Table 1 Demographic information of the participating teachers

Gender	Male	42%	STEM Teaching Experience	1–5 years	80%
	Female	58%		6–10 years	20%
Subject Taught	Science	31%	**Country**	UAE	47%
	Technology	21%		Kuwait	6%
	Math	26%		Qatar	7%
	Engineering	13%		Bahrin	6%
	Business	23%		Oman	12%
Grade Taught	Primary 11%		Secondary 66%	Higher Education 23%	

pre-test data and supplemented by relevant literature pertaining to E-STEM. Five sessions were conducted with a week or two between each, accommodating participants' time preferences and availability.
- **TPD Delivery Mode**: Various delivery modes were employed, incorporating verbal approaches such as explanation and discussion that delved into the theoretical foundations of E-STEM, connecting them to participants' own practices (Avery & Reeve, 2013). Additionally, written materials in the form of booklets and case studies were employed. The hands-on teamwork aspect involved E-STEM group activities geared toward the creation of E-STEM activities as suggested by Jituafua (2020). Furthermore, technology integration played a key role, utilizing interactive platforms like Plickers, Nearpod, and Padlet to provide equal opportunities for engagement and facilitate reflection through sharing ideas and practices (Haas et al., 2021; Eltanahy, 2023a).
- **TPD Resources**: Various resources were created, including a booklet with E-STEM literacy principles aligned with the conceptual framework, distributed to all participants for session guidance and post-TPD support. Case studies were discussed in groups, comparing them to teachers' actual classroom practices. Participants designed charts to reflect understanding and share implementation ideas. Additionally, a variety of technological platforms and tools were utilized to enhance engagement and collaboration among teachers.

Validity of the PD Content and Pedagogy

Prior to putting TPD sessions into actions, all materials underwent a thorough review and validation process by three professors in the faculty of education (Creswell, 2014). The reviewers evaluated the TPD content sequence, the rationale for practices, authentic tasks, assessment, alignment of activities with principles, and ensured that the E-STEM principles were grounded in research. Their feedback improved the TPD structure, influencing the foundational research selection. They also simplified language, pedagogical content, and activities to suit diverse needs of teachers from various backgrounds.

Table 2 The content focus of TPD in E-STEM literacy

Days	TPD Content Focus	E-STEM Literacy Principles
D1	- Discuss current STEM activities. - The main concepts of STEM learning - Rationale behind incorporating E into STEM to become E-STEM	Awareness (Aydogdu et al., 2020)
D2	- Disciplinaries continuum - E-STEM Pully system - Focus of entrepreneurial integration in different learning stages	Integration (Helmane & Briška, 2017; Johannisson, 2010)
D3	- Input-Output- Operation System - Education through entrepreneurship - Competency-based Approach	Pedagogy (Eltanahy, 2023a)
D4	- E-STEM Teaching strategies - E-STEM Strategic Plan	Practice (Eltanahy et al., 2020b)
D5	- Student-competency profile - E-STEM Rubric	Assessment (Eltanahy et al., 2021; Eltanahy, 2024; Eltanahy & Mansour, 2024)

Phase 3 Examining the Impact of E-STEM TPD on Teachers' PG

At the conclusion of the TPD sessions, a posttest was administered to all attending teachers on the last day to examine the impact of E-STEM TPD on changes in teachers' PG associated with familiarity, interest, and confidence in E-STEM literacy, along with their satisfaction regarding the TPD content and delivery format. This helps in understanding their perceptions regarding the E-STEM TPD effectiveness in empowering them to implement E-STEM literacy principles.

Phase 4 Exploring Teachers' Perceptions Regarding E-STEM TPD

Following the initial analysis of the pre-post-tests, focus group interviews were carried out with nine teachers. This approach aims to explore how they perceive specific experiences (Clarke et al., 2023), particularly related to TPDs in E-STEM to promote their PG and empower them to apply E-STEM learning.

Instrument 1 Test

The test was initially developed in alignment with the research objectives and literature on TPD designs for literacy components in integrated disciplines (Clarke & Hollingsworth, 2002; Eltanahy & Mansour, 2022; Pitiporntapin et al., 2023). It comprises six sections including 49 items, with four utilized in the pre-test (39 items) and all six in the post-test (49 items). The first section gathered participants' demographics, while the subsequent three focused on E-STEM familiarity (13 items), interest (13 items), and confidence (13 items). Each of these sections focused on the same E-STEM literacy principles: awareness, integration, pedagogy, practice, and assessment. The fifth section sought feedback on the TPD content (6 items), and the TPD delivery format supporting E-STEM PG of teachers (4 items). To rate responses, a five-point Likert scale was employed for quantitative data collection across all sections. Last section was specifically designed for open-ended questions, aiming to gather qualitative insights of teachers into the impact of TPD in E-STEM on their PG development.

Test Validity & Reliability

To enhance content validity, feedback from three expert reviewers was considered to verify the content relevance, clarity and accuracy of the test items. Some terms were subsequently modified to simplify and improve readability across all sections. The test was then piloted with 31 conveniently recruited E-STEM teachers. Table 3 displays the reliability and internal consistency of items evaluated using Cronbach's Alpha, resulting in a high value of 0.907 calculated through SPSS. Additionally, exploratory factor analysis was conducted to further enhance construct validity, and all items in each section successfully loaded onto their respective constructs (Creswell, 2014).

Table 3 Cronbach's alpha coefficient to measure the reliability of the Study Tool

Test Sections			Sections of E-STEM Literacy Principles					
			Awareness	Integration	Pedagogy	Practice	Assessment	
		Items	3	3	3	2	2	Total
PG Components	Familiarity	13	0.786	0.802	0.768	0.902	0.938	0.839
	Interest	13	0.794	0.822	0.801	0.94	0.929	0.857
	Confi-dence	13	0.787	0.854	0.789	0,968	0.894	0.831
Total E-STEM Literacy Items								0.842
			Sections of Teachers' Satisfactions about the TPD in E-STEM Literacy					
TPD Satisfaction	Content	6						0.896
	Delivery Mode	4						0.975
Total Test Items		49	Overall Cronbach's Alpha Coefficient					0.907

Instrument 2 Interviews

Three semi-structured interviews were conducted post TPD sessions by the lead author with nine UAE teachers representing different CoP within the fields of HE, SE, PE. The design process of the interview outline began with identifying the objective of the interview: to explore their perceptions regarding the development of their PG of E-STEM literacy, including their satisfaction about the TPD content and its delivery mode. The interview protocol was guided by the literature review and the conceptual framework of the study.

To enhance content validity, two experts reviewed the interview protocol and suggested some word edits to improve clarity and eliminate risks of discussing irrelevant points (Chong et al., 2021). Consistent with C-GT and the use of theoretical sampling, data collection persisted until theoretical saturation was achieved. Notably, during the second interview, responses displayed repetition in the emerging analytical categories. By the conclusion of the third interview, it became evident that core categories had reached saturation, suggesting that additional interviews would likely yield minimal new information. The interview protocol was designed with four primary questions.

- What are your perceptions regarding the impact of the E-STEM TPD on your PG of E-STEM literacy?
- How satisfied are you with the TPD to enhance your planning for E-STEM lessons?
- How satisfied are you with the TPD to enhance the implementation of E-STEM?
- How satisfied are you with the TPD to enhance the intended outcomes of E-STEM?

Each focus group interview had a duration of 40–60 min, allowing for probing and providing opportunities for participants to freely reflect on their entire E-STEM experience (Creswell, 2014). Table 4 shows the interviews scheduled based on participants' availability and consent.

Table 4 Focus Group Interview Schedule for Participating Teachers

Interviews	Male	Female	Grade	Subject
Interview 1	2	1	HE	Business & Engineering
Interview 2	2	1	SE	Technology & Math
Interview 3	1	2	PE	Math & Science

HE* Higher Education SE* Secondary Education PE* Primary Education

Table 5 Normality test

Scale	Sub dimension		Skewness		Kurtosis		
			Statistical Value	S. Error	Statistical Value	S. Error	Kolomogorov-Simirnov
Pedagogical Growth	Familiarity	Pretest	0.04	0.16	−0.22	0.32	0.12
		Posttest	-1.11	0.16	0.87	0.32	0.47
	Confidence	Pretest	0.10	0.34	−0.24	0.32	0.21
		Posttest	−0.70	0.16	0.75	0.32	0.38
	Interest	Pretest	0.09	0.16	−0.04	0.32	0.26
		Posttest	−0.85	0.16	−0.60	0.32	0.39
	General	Pretest	−0.01	0.16	−0.34	0.32	0.16
		Posttest	−0.98	0.16	0.11	0.32	0.40

Data Analysis

The quantitative data began with a normality check for the overall scale and each sub-dimension by examining skewness and kurtosis values for pre-test and post-test results (see Table 5).

Table 5 shows that the skewness and kurtosis values of the data fall within the range of +1.5/-1.5 (Tabachnick & Fidell, 2007). Additionally, the Kolmogorov-Smirnov values of the data were examined, and it was determined that the values for the general and sub-dimensions of the scale were greater than $p > .05$ in both pretest and posttest contexts, indicating a standard distribution of scores across all sections of the pre and post-tests which guided the decision for parametric analysis (Knief & Forstmeier, 2021). Subsequently, paired sample-tests were carried out to assess changes in teachers' PG post TPD. Additionally, means and percentages were computed to gauge their satisfaction with the TPD content and delivery format.

Qualitative data from the E-STEM TPD were analysed using a cross-case matrix approach (Table 6) to uncover patterns in participant perceptions and explore the program's effectiveness in equipping teachers with E-STEM capabilities. This analysis, aimed at deeply understanding varying perspectives among HE, SE, and PE teachers from three distinct CoP was guided by the framework of Miles and Huberman (1994). Accordingly, the lead author conducted the interviews, while qualitative coding was a collaborative effort among the research team. Their collective expertise ensured in-depth data analysis, aiming for coder agreement and consistency through collaboration. To ensure consistency, the authors conducted regular meetings to discuss and resolve any discrepancies in coding.

Table 6 facilitated the identification of patterns through coding responses, extracting key themes and subthemes. The coding process followed the conceptual framework and focused on how teachers grow professionally through TPD. This enabled the grouping of codes into

Table 6 T-test results for teachers' PG differences between pre and Post tests

Pre- post test	*N*	X	SD	t- test	df	*p*
Pre - Familiarity	220	26.70	4.77	-106.52	219	0.00
Post - Familiarity	220	57.35	4.12			
Pre- Confidence	220	24.28	3.02	-73.18	218	0.00
Post - Confidence	220	52.37	5.68			
Pre - Interest	220	49.40	3.28	-25.51	219	0.00
Post- Interest	220	58.63	6.05			
Pre - General	220	100.43	8.26	-89.53	218	0.00
Post -General	220	168.47	14.46			

broader themes to provide insights into how TPD positively influenced teachers' E-STEM literacy and teaching strategies.

Findings

The Impact of E-STEM TPD on Teachers' PG Components

To investigate the impact of E-STEM TPD on enhancing teachers' PG components, specifically familiarity, interest, and confidence in E-STEM, a comparative analysis was conducted using paired sample t-tests.

Table 5 presents the results, illustrating the significance of differences between mean scores in the pre-test and post-test assessments. The mean scores for teachers' PG in E-STEM increased favourably towards the post-test across the entire scale and within subdimensions (PGtotal 100.43 to 168.47, PGfamiliarity: 26.70 to 57.35, PGconfidence: 24.28 to 52.37, PGinterest: 49.40 to 58.63). The dependent t-tests indicated statistical significance for each PG component and overall (PGtotal t=-89.53, $p<.05$; PGfamiliarity t=-106.52, $p<.05$; PGconfidence t=-73.18, $p<.05$; PGinterest t=-25.51, $p<.05$).

Teachers' Satisfaction about the TPD in E-STEM

To address the second research question examining teachers' satisfaction level about the TPD content and its delivery format, visual representations in the form of Figs. 3 and 4 were generated to present quantitative data reflecting participants' evaluations.

Figure 3 shows strong participant satisfaction with E-STEM TPD content. Preparation scored 4.79 (96% satisfaction), suggesting relevance to STEM teaching. Implementation scored even higher at 4.87 (97% satisfaction), indicating significant support for planning STEM sessions and integrating entrepreneurial principles. Outcome measures (means 4.2 to 4.61, 84–92% satisfaction) reflect positive perceptions of TPD's efficacy in fostering students' E-STEM competencies and community value projects. Overall, high satisfaction rates underscore TPD's effectiveness in E-STEM learning.

Figure 4 shows high participant satisfaction with diverse E-STEM TPD delivery formats. Mean satisfaction scores ranged from 4.61 to 4.82, indicating consistently high levels. Technology integration had the highest satisfaction at 4.82, yielding a 96% satisfaction rate. Overall, participants expressed over 90% satisfaction for all formats, reflecting positive perceptions of E-STEM TPD's effectiveness in engaging teachers with diverse methods.

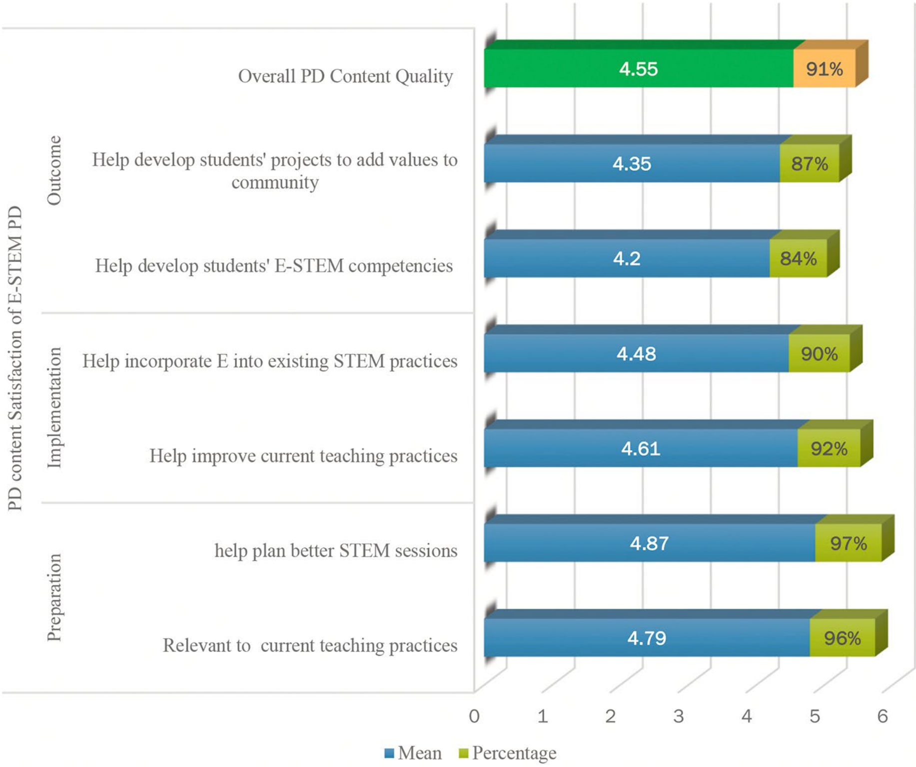

Fig. 3 Teachers' Satisfaction about the TPD Content in E-STEM

Teachers' Perceptions about the E-STEM TPD

Table 6, presenting actual teacher quotes, highlights the favourable reception of the E-STEM Teachers' TPD program across educational levels in different CoP. It unveils how the TPD enhances crucial aspects of E-STEM education, including awareness, integration, pedagogy, practices, and assessment. This feedback highlights the TPD's key role in advancing teachers' PG by boosting their familiarity, interest, and confidence in E-STEM concepts, which is essential for effectively designing, implementing, and anticipating the outcomes of E-STEM initiatives. The analysis identifies significant themes, including the impact of TPD (raising E-STEM confidence), preparation (refining E-STEM strategy), implementation (shifting to an E-STEM culture), and outcomes (diverse TPD effects among CoPs) (See Table 7).

Raising E-STEM Confidence

Teachers' responses indicate a growing confidence in integrating entrepreneurial principles into STEM education, particularly among those previously less involved in STEM. Key insights from TPD sessions, such as E-STEM literacy principles and diverse pedagogical strategies, have empowered teachers to experiment with E-STEM approaches. Positive

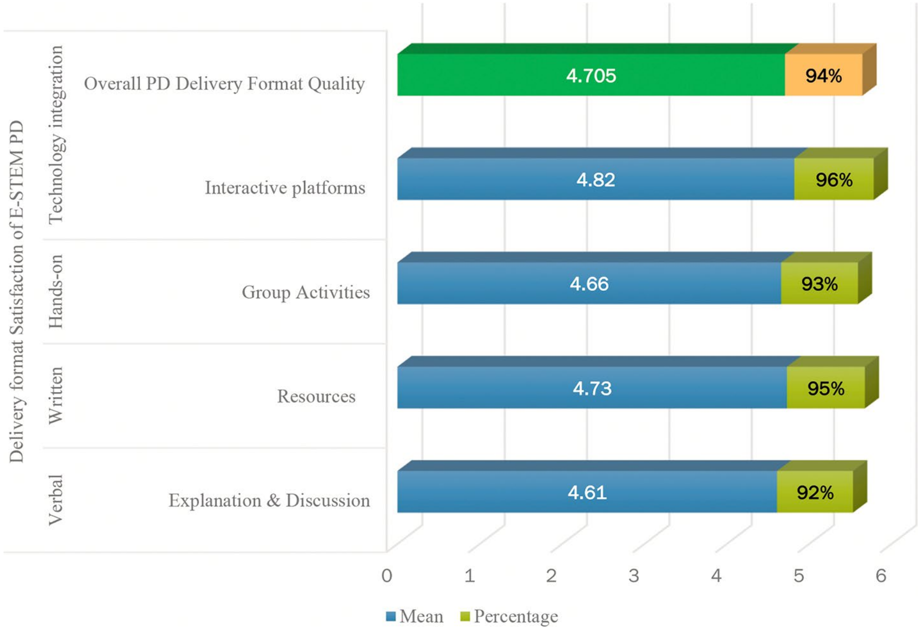

Fig. 4 E-STEM TPD Delivery Format Satisfaction

feedback on the clarity and relevance of E-STEM concepts, like the Input-Operation-Output approach, further demonstrates teachers' enthusiasm for applying these principles in their classrooms. Their willingness to engage in additional E-STEM PDs underscores their eagerness to deepen their understanding and share best practices. This fosters an interdisciplinary teaching environment, ensuring educators from diverse backgrounds find applicability in E-STEM principles and enrich the educational landscape with innovative strategies.

Refining E-STEM Strategy

The success of the TPD stemmed from its emphasis on strategic E-STEM planning across educational levels, fostering teachers' readiness to implement advanced strategies. Valuable resources like high-quality publications and practical tools refined lesson plans, guiding a strategic curriculum approach. Understanding market needs and forming skill-based groups highlighted a focus on impactful project design, while emphasis on project-based learning and real-world problem-solving prepared students for future roles. Teachers' enthusiasm to integrate E into STEM reflects their concerted effort to refine E-STEM strategies, enriching overall STEM learning quality.

Shifting to an E-STEM Culture

The narrative underscores a cultural shift within different CoP towards embracing E-STEM learning, indicating a broader recognition of its significance in enriching student learning experiences. Embracing project-based problem-solving and competency-based approaches, teachers aim to integrate E into STEM practices. They plan to utilize TPD resources as road-

Table 7 Cross-case Matrix linking CoP perceptions in E-STEM TPD

CoP	Trained Teachers	Academic Background	TPD Impact on E-STEM PG	E-STEM Preparation	E-STEM Implementation	E-STEM Outcomes
Higher Education CoP	HE 1	Business	Confident about integrating E into STEM, was not involved in STEM before.	Learned advanced strategies for future E-STEM course planning.	PD sparked ideas for innovative E-STEM teaching methods	New research agenda for college students to investigate E-SETM literacy and enhance skill-workforce.
	HE 2	Business	Many take away points, especially, five E-STEM Literacy principles.	PD provided high ranked publications to integrate cutting-edge research into my E course.	Focus on project-based problem solving for E-STEM.	E-STEM rubric as a formative tool to measure success of E-STEM projects.
	HE 3	Engineering	Became aware of diverse pedagogical strategies of E-STEM to give it a try.	E-STEM booklet is a valuable guide for planning.	Learned applicable E-STEM literacy principles to put into action.	Student-competency profile is an important guiding tool to enhance students' skills
Secondary Education CoP	SE 1	Technology	Excellent PD, E-STEM is interesting. Looking forward to apply with high school students.	Practical planning tools like E-STEM strategic plan will guide my lesson plan.	I will use the E-STEM strategic plan as an implementation roadmap. This will attract talented students.	Help students develop entrepreneurial mindset and skills, including financial awareness, while utilizing technological advancements.
	SE 2	Technology	Input-Operation-Output approach of E-STEM is clear and relevant to integrate E with technology.	Learned guiding students to design impactful E-STEM projects by understanding market needs.	Enjoyed E-STEM scenario-based analysis and will apply the same approach.	In addition to enhancing technological advancement, PD creates a new entrepreneurial focus for integration.
	SE 3	Math	E-STEM Rationale made me aware of the need for integration.	Form skill-based groups, not size-based of E-STEM students	Emphasizing competency-based approach for integrating E into STEM.	E-STEM offers meaningful opportunities for students to become more competent.

Table 7 (continued)

CoP	Trained Teachers	Academic Background	TPD Impact on E-STEM PG	E-STEM Preparation	E-STEM Implementation	E-STEM Outcomes
Primary Education CoP	PE 1	Math	PD is very effective to have good E-STEM projects for all grades.	PD examples inspiring for STEM projects integrating E focus in early years.	I can develop my students' STEM projects by incorporating the E.	Fostering love for E-STEM from an early age to enhance confidence and enthusiasm.
	PE 2	Science	Education-through E-STEM justified E integration into STEM in primary.	Inspired to plan age-appropriate E-STEM activities.	Early exposure to E-STEM concepts in elementary as groundwork for future implementation.	PE students will represent their identity when they learn to create an E-STEM group logo or choose an avatar
	PE 3	Science	Keen to join more E-STEM PDs to continue learning and share practices.	Prepare E-STEM lessons focusing on integrating E basic skills into primary STEM.	PD hands-on activities influenced teaching style, developing my skills to be an entrepreneurial teacher	It will enhance innovation and some students will show interest to be Businessmen in the future.

maps and capitalize on scenario-based analysis to attract talented students. Recognizing the importance of early exposure to E-STEM concepts, PE teachers are laying the groundwork for future implementation efforts. The influence of hands-on activities from TPD sessions underscores the transition towards a more experiential and student-centered approach.

TPD Effects across CoPs

The analysis reveals nuanced differences between CoPs regarding adaptation to academic backgrounds, strategic planning, pedagogical focus, and perceived outcomes. CoP of HE teachers emphasized interdisciplinary aspects and advanced research, while CoPs of PE and SE focused on practical implementation and fostering early engagement with E-STEM.

Accordingly, The TPD fosters recognition of its value across various educational levels, showcasing diverse adaptations of E-STEM integration. This narrative encapsulates the transformative impact of the TPD, promoting interdisciplinary integration, enhancing pedagogical diversity, and preparing teachers and students for the demands of the 21st century.

Discussion

This study contributes to the E-STEM field through providing results regarding the effectiveness of TPD on enhancing teachers' E-STEM PG.

The t-test data that represent the impact of the TPD on teachers' E-STEM literacy reveals a significant positive impact of E-STEM PD on enhancing teachers' PG components, including familiarity, interest, and confidence in E-STEM context. The mean scores of teachers' PG increased across all components from pre-test to post-test, indicating a substantial improvement in their competencies. The observed improvements in the three PG components align with the expectations derived from the literature review, supporting the idea that TPD positively influences teachers' pedagogy to integrate E-STEM literacy into their teaching practices (Clarke & Hollingsworth, 2002; Margot & Kettler, 2019). This is consistent with previous studies highlighted the necessity of supporting teachers' PG in the context of E-STEM (Pitiporntapin et al., 2023; Birdthistle et al., 2023; Sahin et al., 2024).

Furthermore, the study's theoretical contribution lies in its innovative merger of the two established models, STEM Literacy model and IMPG to form the conceptual framework. This integration provides a new perspective on understanding the PG development of teachers within the E-STEM setting. The TPD strategically concentrates on developing teachers' E-STEM pedagogical knowledge (familiarity), skills (confidence), and attitude (interest) towards E-STEM learning. This TPD responds directly to the identified gaps in teacher preparation for integrated disciplines and aligns with the broader educational shift towards a knowledge-based economy (Siddiqui & Afzal, 2022).

The participants' positive feedback on the relevance of TPD content to current teaching practices suggests that the E-STEM TPD is well-aligned with teachers' diverse needs. This alignment is in keeping with the perspectives shared by Pitiporntapin et al. (2023), highlighting the significance of customizing TPD to meet the unique challenges and requirements of teachers in integrated disciplines. This response suggests that the TPD content aligns well with the demands of STEM teaching, establishing a robust foundation for E-STEM integration. This highlights the importance of well-designed TPDs that provide takeaway materials that contains key theories, rationale, activities, assessment transforms the TPD content into a valuable resource for teachers in their daily activities (Darling-Hammond, 2017; Kennedy, 2019; Boulay, 2023; Özer & Suna, 2023). Addressing current challenges in E-STEM education and equipping teachers with applicable tools is crucial for continuous PG. This, in turn, empowers educators to showcase a practical impact of the TPD on teaching practices (Kosanovich & Rodriguez, 2024).

Teachers' positive responses affirm the effectiveness of E-STEM PD. They strongly agreed that the provided TPD content is relevant for improving their current STEM practices and enhancing their capacity to integrate entrepreneurship into existing STEM activities. This alignment further supports the perceived efficacy of the PD in fostering teachers' effective practices and students' competencies (Asaoka, 2021). This is consistent with Pihie and Bagheri (2011), who explained that to effectively nurture entrepreneurial teachers, TPDs should support them to combine their passions, ideas, and practical actions to foster innovation and lead change in educational settings This involves recognizing opportunities, taking risks, and implementing innovative solutions within their E-STEM teaching practices.

Teachers were highly satisfied with various TPD delivery modes, including verbal instruction, written resources, hands-on activities, and technology integration. Positive feedback on verbal instruction aligns with the value participants placed on explanations and discussions in E-STEM TPD, in line with Clark & Mayer (2016). The favourable response to written resources supports their role as valuable references, reinforcing key concepts as noted by Pitiporntapin et al. (2023). High satisfaction with hands-on activities underlines the importance of experiential learning, enhancing practical understanding and implementation strategies, as suggested by Gardner et al. (2019). The positive reception of technology integration reflects the importance of digital tools in TPD, aligning with contemporary education trends as emphasized by Eltanahy (2023b) and Eltanahy et al. (2020b). Accordingly, the diverse TPD delivery formats effectively met teachers' expectations through providing an engaging learning experience that caters to diverse preferences and learning styles.

PE teachers exhibit excitement about designing engaging E-STEM sessions and emphasize the need for early exposure to E-STEM concepts. Their focus is on fostering a love for E-STEM from an early age to enhance students' confidence and enthusiasm. Additionally, they see the potential for students to represent their identities through E-STEM group activities. The elevated satisfaction perceptions about the implementation phase, underscore the E-STEM PD's efficacy in helping teachers plan better STEM sessions and enhance their teaching practices. This is consistent with the role of PD emphasized by (Clarke & Hollingsworth, 2002) in transforming teaching practices and fostering PG. These positive perceptions suggest that the PD content provides practical strategies for effective implementation which in order empower teachers to navigate the challenges associated with E-STEM integration (Eltanahy et al. 2020b); Yoon, 2007).

The high satisfaction among teachers with the variety of TPD delivery methods, including verbal instruction, written materials, hands-on activities, and technology integration, suggests significant implications for structuring future PD initiatives. The effectiveness of verbal instruction in providing clear explanations and fostering interactive discussions echoes findings by Clark & Mayer (2016) about interactive learning's value. Written resources' role as valuable, enduring references for reinforcing key concepts aligns with insights from Pitiporntapin et al. (2023), while the positive reception of hands-on activities highlights experiential learning's importance in deepening practical understanding, a point supported by Gardner et al. (2019). Additionally, the embrace of technology integration speaks to the increasing relevance of digital tools in education, as noted by Eltanahy (2023a). These facets collectively underscore the E-STEM TPD program's success in meeting teachers' diverse preferences and learning styles, offering a compelling model for future TPD efforts that seek to maximize engagement and educational effectiveness through a multifaceted instructional approach.

Implications

The positive outcomes of this study affirm the effectiveness of the innovative conceptual framework that integrates STEM Literacy model with IMPG, highlighting its relevance in enhancing E-STEM literacy among STEM teachers. Hence, the focus on entrepreneurial infusion through E-STEM prepares teachers and students alike for future challenges and opportunities. Well-structured TPDs play a crucial role in enriching teachers' E-STEM knowledge and skills, essential for effective integration of E-STEM principles in teaching. These advancements significantly contribute to the transition toward a knowledge-based economy by prioritizing transferable skills in TPDs. This enables educators to better apply classroom knowledge to real-world issues, thereby enhancing teaching practices and student achievements. Educational leaders, curriculum developers, and policymakers can utilize these insights to design TPDs promoting E-STEM literacy and practices, aiming to foster an entrepreneurial spirit within STEM education.

Conclusion

The findings suggest that tailored TPD content, spanning five key E-STEM literacy principles, positively influences teachers' pedagogy and integration of E-STEM principles into their teaching practices. These results established a coherent link between E-STEM TPD and a substantial enhancement in teachers' PG within the E-STEM learning. Teachers' PG, including familiarity with E-STEM knowledge, interest in E-STEM and its applications, and confidence in applying E-STEM activities, significantly increased through structured TPD that focuses on the five E-STEM literacy principles: awareness, integration, pedagogy, practice, and assessment. As the emphasis on a knowledge-based economy persists, the imperative need to invest in effective PDs becomes apparent. This finding suggests that supporting teachers' PG in integrated disciplines, particularly E-STEM literacy, is essential for nurturing a workforce well-equipped with the skills necessary for success in E-STEM planning, implementing and achieving outcomes. The high satisfaction levels across various delivery formats and TPD content underscore the success of the E-STEM TPD in employing a well-balanced approach to cater to participants' diverse learning preferences. This, in turn, aligns with the goals of iSTEMed. This study reinforces the importance of incorporating a mix of instructional methods, including verbal, written, hands-on, and technology-integrated approaches, to enhance the overall quality and effectiveness of TPD in E-STEM.

This emphasizes the importance of well-designed TPD content tailored to teachers' needs, providing essential theories and methods as takeaway materials. Such TPD content serves as a valuable ongoing resource, especially when addressing current E-STEM challenges and offering directly applicable tools for classroom use. This continuous support is vital for teachers' PG, as empowerment and practical implications of TPD positively influence education quality. Consequently, improved E-STEM literacy among teachers through TPDs could enhance the overall education system, attracting talent and nurturing students' entrepreneurial mindset.

Limitation of the Study

Despite its contribution, this study has limitations. The quasi-experimental design with a single group may impact the generalizability of findings. The context-specific nature of the study, conducted primarily in the middle east, may limit broader applicability. While the selection criteria for teachers aimed to encompass diverse backgrounds, levels of teaching experience, and geographical locations to ensure a broad range of perspectives on E-STEM education, this approach may introduce biases due to self-selection and the specific demographics of attendees. Nevertheless, this study initiates a new agenda of exploration into the PG of teachers in the E-STEM context. Future investigations should expand their scope to include diverse contexts to provide a more comprehensive understanding of E-STEM learning. A particularly interesting avenue for future research involves examining the possible relationship between the three components of PG to contribute to the refinement of E-STEM goals and strategies for more widespread implementation in various CoP within educational settings.

Funding Statement Not applicable.

Data Availability To protect the study participants' privacy, the datasets used and analysed during this study are available from the corresponding author on reasonable request.

Declarations

Conflict of Interest The authors declare that they have no conflict of interest.

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