Technology-Enabled Professional Development Practices in Relation to Education 4.0 Skills among Preservice Teachers

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Abstract
Continuous advancements in educational technology and the emergence of Education 4.0 have substantially transformed the expectations of preservice teachers in teacher education institutions(Başgül & Coştu, 2025). This study examined the relationship between technology-enabled professional development practices and Education 4.0 skills among preservice teachers in India. This inquiry adopted a quantitative, correlational survey framework. Data were gathered from 400 preservice teachers selected through purposive convenience sampling from teacher education institutions across India, via a structured Google Form distributed over a six-week period. Two self-developed instruments were used: the Technology-Enabled Professional Development Practices Scale (TEPDPS), comprising 25 items across five dimensions, and the Education 4.0 Skills Scale (E4SS), comprising 35 items across seven dimensions. Pilot testing with 50 preservice teachers yielded alpha coefficients of 0.910 for TEPDPS and 0.935 for E4SS, and dimension-level alphas ranged from 0.718 to 0.752 for TEPDPS and from 0.719 to 0.749 for E4SS, all meeting or exceeding the acceptable threshold of 0.70 (Nunnally, 1978). The results showed that preservice teachers had moderate to above-average levels of technology-enabled professional development practices (M = 93.76, SD = 9.28) as well as Education 4.0 skills (M = 134.19, SD = 12.58). Bivariate assessment showed a statistically significant moderate positive correlation between both primary indicators (r = 0.490, p <.001). This implies that higher levels of engagement with technology-enabled professional development are associated with better Education 4.0 skills. The analysis further showed no significant differences on gender, type of institution or locality. These findings indicate that technology-supported professional learning contributes to student teachers' development of the needed teaching skills for Education 4.0 environments.

Keywords: Preservice Teachers, Technology-enabled Professional Development, Education 4.0 skills, Digital Competency, Teacher education.

Introduction

As classrooms across India adopt more digital teaching resources, the foundational frameworks for training future educators are undergoing a necessary transformation. (Imran et al., 2025). With the emergence of Education 4.0, teachers are now expected to develop competencies that match the needs of technology-driven educational environments and the broader demands of the Fourth Industrial Revolution (Aziz Hussin, 2018). As a result, teacher education institutions are placing greater attention on the quality and effectiveness of professional development practices provided to preservice teachers. Technology-enabled professional development includes various digitally supported learning activities that help teachers improve their professional knowledge and teaching competencies (Trust et al., 2016). These activities may include webinars, online courses, collaborative learning through learning management systems (LMS), ICT-integrated teaching

practice, and reflective learning using digital platforms. Researchers have suggested that such practices can strengthen both pedagogical understanding and the ability of preservice teachers to work effectively in technology-rich classrooms (Prestridge, 2019). Education 4.0 skills generally encompass data fluency, analytical reasoning, innovative ideation, collective teamwork, interpersonal expression, troubleshooting capabilities, and autonomous study habits (Gleason, 2021). The study used a correlational survey method to find the relationship between the selected factors. Data were collected using self-developed instruments that were tested for validity and reliability based on the framework suggested by(D.R Goel & Chhaya Goel, 2016)

Need and significance of the study

(Ministry of Education, Government of India, 2020) The increasing integration of educational technology has created new expectations for teacher education institutions in India. The NEP 2020 highlights the significance of integrating technology into the preparation of prospective teachers and professional development programmes. In a similar way, the NCFTE emphasises the necessity to prepare future teachers who can use technology effectively to support student learning (NCFTE, 2009). At the same time, Education 4.0 has increased the demand for key attributes, including digital fluency and autonomous study habits, paired with essential workplace skills like collaborative problem-solving and effective team communication among preservice teachers (Almutawa, 2025). Although many teacher education institutions have started using technology-supported professional learning activities, limited empirical research is available on whether these practices actually contribute to the development of Education 4.0 skills among preservice teachers in the Indian context (Sheikh & Nath, 2026). The digital shift during the covid time had opportunities and challenges for professional learning(Mhlongo et al., 2023). Understanding the nexus between practices of technology-enabled capacity building initiatives and development of Education 4.0 skills is therefore not just an abstract concept but rather a critical input for curriculum design, institutional policy and teacher training reform(Chigbu et al., 2023). This study aims to fill this gap by providing empirical data from a nationwide sample of preservice teachers, which can be a strong basis for future decisions for teacher educators, policymakers, and curriculum designers (Yüceer-Öztürk & Tan-Şişman, 2025).

Review of related literature

Technology-Enabled Professional Development

Professional development practices mediated by digital technologies have emerged as a significant area of scholarly inquiry For the last twenty years, we have seen (Fernandes et al., 2020). And (Segev et al., 2026) demonstrated that teachers who engage with online professional learning networks report enhanced pedagogical knowledge and greater confidence in technology use. As same (Dede et al., 2009) reported that technology-mediated professional development can improve teaching practices when it includes collaborative learning, reflective activities, and subject-specific applications. Compared to traditional face-to-face workshops, such approaches were found to have more lasting effects on teachers' professional growth. In the Indian context (Ramdana et al., 2026) found that B.Ed. Student teachers who used LMS platforms and digital tools during their teaching practice showed better pedagogical understanding and greater confidence in using technology for teaching. (Wang & Fan, 2025) also identified that participation in virtual peer learning networks helped preservice teachers strengthen reflective learning and collaborative teaching practices when compared with those who depended mainly on conventional training approaches.

Education 4.0 Skills and Teacher Competency

Education 4.0 emphasizes skills like digital literacy, creativity, communication, collaboration, critical thinking, problem-solving, and self-directed learning in order to prepare students and

educators for quickly evolving technological and industrial environments (Tikhonova & Raitskaya, 2023). It emphasises skills such as digital literacy, creativity, communication, collaboration, critical thinking, problem-solving, and self-directed learning (Aziz Hussin, 2018; Voogt & Roblin, 2012). A comparative review conducted by (Erstad & Voogt, 2018) also highlighted the importance of these competencies in various international twenty-first century curriculum frameworks.

According to (Tondeur et al., 2017) When technology is consistently incorporated into teacher education programs rather than being taught through distinct modules, preservice teachers are more likely to acquire digital abilities. Similarly, (Ali et al., 2024) discovered that potential teachers in India who took part in organized training in digital pedagogy demonstrated improved critical thinking, creativity, and team problem-solving abilities. These results point to a potential connection between preservice teachers' acquisition of Education 4.0 abilities and technology-enabled professional learning. However, survey-based research does not allow for the direct drawing of causal inferences.

Research Gap

Existing studies have examined technology-enabled professional development and Education 4.0 skills separately in different educational contexts. However, very few research has looked into how these two characteristics relate to one another among preservice teachers in India (Souza & Debs, 2024). Numerous earlier researches have mostly concentrated on small regional samples, particular institutions, or in-service teachers. Furthermore, a few of research have mostly used qualitative methods, which restricts how broadly the results may be applied (Munezero et al., 2026).

Methodology

Research Design

A quantitative, correlational survey design was used for this investigation. When the researcher wants to characterize the state of specified variables and ascertain the kind and degree of the link between them without conducting experiments, this approach is suitable (Aggarwal & Ranganathan, 2019). The study neither manipulated variables nor assigned participants to conditions; instead, it described existing levels of technology-enabled professional development practices and Education 4.0 skills and examined the relationship between them.

Objectives of the Study

1. To study the level of technology-enabled professional development practices among preservice teachers.
2. To study the level of Education 4.0 skills among preservice teachers.
3. To determine the relationship between technology-enabled professional development practices and Education 4.0 skills among pre-service teachers.
4. To examine differences in technology-enabled professional development practices among preservice teachers based on selected demographic variables.
5. To examine differences in Education 4.0 skills among preservice teachers based on selected demographic variables.

Hypotheses of the Study

- Technology-enabled professional development practices are not significantly related to Education 4.0 skills among preservice teachers.
- Technology-enabled professional development practices do not significantly vary across gender among preservice teachers.
- Education 4.0 skills do not differ significantly between male and female preservice teachers.

- The type of institution does not create a significant difference in technology-enabled professional development practices among preservice teachers.
- No significant difference exists in Education 4.0 skills among preservice teachers with regard to the locality of the institution.

Population and Sample

The population of the study comprised preservice teachers enrolled in teacher education programmes (B.Ed., Integrated B.Ed., and M.Ed.) across India and A total of 400 preservice teachers participated in the study (Sarangapani, 2025). The sample was selected purposive convenience sampling from government, government-aided, and private teacher education institutions located in both rural and urban areas. Data were collected using a Google Form that was shared through institutional contacts, teacher education groups, and academic social media platforms over six weeks.

Tools Used for the Study

Data were collected using two self-developed rating scales constructed on a five-point Likert format, 1 = Strongly Disagree to 5 = Strongly Agree (Joshi et al., 2015).

Technology-Enabled Professional Development Practices Scale (TEPDPS). A 25-item scale organised across five dimensions: Digital Professional Learning (5 items), ICT Integration Practices (5 items), Collaborative Digital Learning (5 items), Reflective Technology Practices (5 items), and Self-Directed Technology Learning (5 items). The minimum possible score is 25, and the maximum is 125 (Astiena et al., 2026).

Education 4.0 Skills Scale (E4SS), A 35-item scale organised across seven dimensions: Digital Literacy (5 items), Critical Thinking (5 items), Creativity and Innovation (5 items), Communication (5 items), Collaboration (5 items), Problem Solving (5 items), and Self-Directed Learning (5 items). The minimum possible score is 35, and the maximum is 175 (Aziz Hussin, 2018; Gleason, 2021; Voogt & Roblin, 2012).

Validity and Reliability

Both scales were subjected to face and content validity review by a panel of five experts comprising teacher educators, educational technologists, and research methodology specialists (Kusi Amponsah et al., 2020). Items were revised, reworded, or deleted based on expert feedback. Following validation, a pilot study was conducted with 50 preservice teachers not included in the final sample. Reliability analysis using Cronbach's alpha yielded coefficients of 0.910 for TEPDPS and 0.935 for E4SS, indicating high internal consistency (Mallery, Paul, 2003). Dimension-level alpha values ranged from 0.718 (Collaborative Digital Learning) to 0.752 (Digital Professional Learning) for TEPDPS, and from 0.719 (Collaboration) to 0.749 (Creativity and Innovation) for E4SS, as detailed in Table 2. All dimensional alpha coefficients met or exceeded the acceptable threshold of 0.70 (Nunnally, 1978; Tavakol & Dennick, 2011).

Common Method Variance Diagnostic

Since all the variables were assessed through a single self-report measure, we tested the risk of common method variance (CMV) using Harman's single-factor test (Harman, David, 1967; Podsakoff et al., 2003). An unrotated principal components analysis was performed on the 60 items of both scales. The first factor explained 9.09% of the total variance, which is below the 50% cut-off value often used as an indication of problematic (Podsakoff et al., 2003). The variance structure was spread across several factors with no one factor being dominant. The results suggest that common method bias is not a substantial threat to the validity of the relationships reported in this study, but we recognize the limitations inherent in concurrent self-report measurement.

Statistical techniques used

The following statistical methods were used to analyze the data that was collected: Mean and standard deviation are used to evaluate the values of the two primary variables, whereas frequency counts and percentages are used to describe the respondents' demographic profile. And to determine the scales' reliability, use Cronbach's alpha coefficient (Taber, 2018). Pearson product-moment correlation for testing the relationship between the two variables (H_{01}) (Schober et al., 2018b); independent samples t-test for testing significant differences based on gender (H_{02}, H_{03}) and locality of institution (H_{05}); and one-way analysis of variance (ANOVA) for testing significant differences based on type of institution (H_{04})(Nigam & Kar, 2025). IBM SPSS Statistics (Version 29) was used for all analysis, while R (Version 4.3.2) was used for verification (Haider et al., 2026). In addition, the risk of common method variance was tested by unrotated principal component analysis of all 60 items, using Harman's single-factor test.

Analysis and interpretation

The respondents' demographic profile

The demographic distribution of the 400 preservice teachers that took part in the study is shown in Table 1

Table 1

Respondents' Demographic Profile (N = 400)

Demographic Variable	Category	Frequency (f)	Percentage (%)
Gender	Male	161	40.25
	Female	232	58.00
	Prefer not to say	7	1.75
Age Group	Below 20	36	9.00
	20–22	185	46.25
	23–25	134	33.50
	Above 25	45	11.25
Course	B.Ed.	211	52.75
	Integrated B.Ed.	85	21.25
	M.Ed.	74	18.50
	Other	30	7.50
Semester	First	120	30.00
	Second	94	23.50
	Third	106	26.50
	Fourth	80	20.00
Type of Institution	Government	102	25.50
	Government Aided	133	33.25
	Private	165	41.25
Locality	Rural	161	40.25
	Urban	239	59.75
Attended Online PD	Yes	274	68.50
	No	126	31.50

Note. N = 400. PD = Professional Development Programme.

The sample included 232 female preservice teachers (58.00%) and 161 male preservice teachers (40.25%), while 7 participants (1.75%) preferred not to disclose their gender. Most respondents belonged to the 20-22 age group (46.25%), which is common in teacher education programmes at the undergraduate level. B.Ed. Students formed the largest group in the sample (52.75%).

Participants were drawn from government, government-aided, and private institutions, with private institutions representing the highest proportion (41.25%). In addition, 68.50% of the respondents reported that they had attended at least one online professional development programme during the previous year, suggesting a reasonable level of exposure to technology-supported professional learning activities.

Reliability of the Scales

Based on the pilot research with fifty preservice teachers, Table 2 displays the Cronbach's alpha values for both the overall scales and each of their separate aspects.

Table 2

Reliability Statistics: Cronbach's Alpha Coefficients (Pilot Study, n = 50)

Scale / Dimension	No. of Items	Cronbach's Alpha (α)
TEPDPS Overall	25	0.910
D1: Digital Professional Learning	5	0.752
D2: ICT Integration Practices	5	0.731
D3: Collaborative Digital Learning	5	0.718
D4: Reflective Technology Practices	5	0.744
D5: Self-Directed Technology Learning	5	0.727
E4SS Overall	35	0.935
D1: Digital Literacy	5	0.738
D2: Critical Thinking	5	0.726
D3: Creativity & Innovation	5	0.749
D4: Communication	5	0.741
D5: Collaboration	5	0.719
D6: Problem Solving	5	0.733
D7: Self-Directed Learning	5	0.726

Note. TEPDPS = Technology-Enabled Professional Development Practices Scale; E4SS = Education 4.0 Skills Scale. Reliability coefficients greater than 0.70 were considered acceptable based on the criterion suggested by (Tavakol & Dennick, 2011).

Table 3 presents the descriptive statistics for the TEPDPS dimensions and overall scale.

Table 3

Descriptive Statistics: TEPDPS Dimensions and Overall Scale (N = 400)

Dimension	M	SD	Level
D1: Digital Professional Learning	3.77	0.72	Above Average
D2: ICT Integration Practices	3.70	0.67	Above Average
D3: Collaborative Digital Learning	3.73	0.67	Above Average
D4: Reflective Technology Practices	3.74	0.68	Above Average
D5: Self-Directed Technology Learning	3.81	0.65	Above Average
TEPDPS Overall Score	93.76	9.28	Moderate–Above Average

Note. M = Mean; SD = Standard Deviation. Dimension scores were calculated on a 1–5 scale, while the overall score ranged from 25 to 125. Based on tertile classification, scores were grouped into low (≤ 87.00), moderate (87.01–103.00), and high (> 103.00) categories.

The mean score for TEPDPS was 93.76 (SD = 9.28), which suggests a moderate to above-average level of technology-enabled professional development practices among preservice teachers. Tertile classification showed 34.00% of the respondents were classified as low, 33.25% as intermediate

and 32.75% as high. And 131 (32.75%) at the high level. Average scores on the five-point scale ranged from 3.70 (ICT Integration Practices) to 3.81 (Self-Directed Technology Learning) and all scores indicated above average engagement. The highest mean score was found for the dimension of Self-Directed Technology Learning which indicates that the preservice teachers are most proactive to explore and update their knowledge about educational technologies independently.

Level of Education 4.0 Skills (Objective 2)

The descriptive statistics for the E4SS dimensions and overall scale are shown in Table 4.

Table 4

Descriptive Statistics: E4SS Dimensions and Overall Scale (N = 400)

Dimension	M	SD	Level
D1: Digital Literacy	3.86	0.70	Above Average
D2: Critical Thinking	3.80	0.68	Above Average
D3: Creativity & Innovation	3.83	0.68	Above Average
D4: Communication	3.87	0.69	Above Average
D5: Collaboration	3.83	0.67	Above Average
D6: Problem Solving	3.84	0.65	Above Average
D7: Self-Directed Learning	3.81	0.69	Above Average
E4SS Overall Score	134.19	12.58	Moderate–Above Average

Note. M = Mean; SD = Standard Deviation. Dimension scores are on a 1–5 scale; overall score on a 35-175 scale. Level classification based on tertile split: Low (≤ 126.00), Moderate (126.01-145.00), High (> 145.00).

On a scale of 35 to 175, the total mean score on the E4SS was 134.19 (SD = 12.58). 135 respondents (33.75%) were at the low level, 137 (34.25%) were at the intermediate level, and 128 (32.00%) were at the high level, according to tertile-based categorization. Across all seven dimensions, mean scores ranged from 3.80 (Critical Thinking) to 3.87 (Communication), all within the above-average range. The relatively uniform distribution across dimensions suggests that preservice teachers perceive their Education 4.0 competencies as broadly balanced, without notable gaps in any specific domain.

Relationship between Technology-Enabled Professional Development Practices and Education 4.0 Skills (Objective 3 H_{01})

The Pearson product-moment correlation analysis findings are shown in Table 5.

Table 5

Pearson Product-Moment Correlation between TEPDPS and E4SS (N = 400)

Variables	M	SD	Pearson r	p-value	Decision
TEPDPS (IV)	93.76	9.28	-	-	-
E4SS (DV)	134.19	12.58	0.490**	< .001	H_{01} Rejected

The Pearson product-moment correlation analysis revealed a significant positive moderate relationship between technology-enabled professional development practices and Education 4.0 skills among preservice teachers ($r = 0.490$, $p < .001$) (Gupta & Dua, 2025). This indicates that preservice teachers who demonstrated higher levels of engagement with technology-enabled professional development practices also tended to report higher levels of Education 4.0 competencies (León et al., 2026). The obtained r value of 0.490 falls in the moderate range according to (Cohen, 1988) classification. Accordingly At the significance level of 0.001, the null hypothesis H_{01}, which claimed that the two variables had no meaningful association, was rejected.

Predictive Contribution of TEPDPS Dimensions on Education 4.0 Skills

To determine which specific dimensions of technology-enabled professional development practices significantly predict Education 4.0 skills, a multiple linear regression analysis was conducted with the five TEPDPS dimensions as predictors and E4SS Total Score as the outcome variable. The model was statistically significant ($F(5, 394) = 10.892$, $p < .001$), explaining 12.1% of the variance in Education 4.0 skills ($R^2 = .121$, Adjusted $R^2 = .110$). The regression coefficients are presented in Table 5.1.

Table 5.1

Multiple Linear Regression: TEPDPS Dimensions Predicting E4SS Total Score (N = 400)

Predictor	B	SE	β	t	p
Constant	103.171	5.305	-	-	-
D1: Digital Professional Learning	0.355	0.156	0.109	2.284	.023*
D2: ICT Integration Practices	0.318	0.160	0.096	1.991	.047*
D3: Collaborative Digital Learning	0.541	0.150	0.174	3.613	< .001***
D4: Reflective Technology Practices	0.508	0.149	0.163	3.402	.001**
D5: Self-Directed Technology Learning	0.368	0.153	0.115	2.412	.016*

Note. B = unstandardized coefficient; SE = standard error; β = standardized coefficient; R = .348; $R^2 = .121$; Adjusted $R^2 = .110$; $F(5, 394) = 10.892$, $p < .001$. *p < .05. **p < .01. ***p < .001.

All five TEPDPS dimensions were statistically significant predictors of Education 4.0 skills. Collaborative Digital Learning ($\beta = .174$, $p < .001$) and Reflective Technology Practices ($\beta = .163$, $p = .001$) emerged as the strongest predictors, suggesting that preservice teachers who engage in peer-based digital collaboration and use technology for structured professional reflection demonstrate meaningfully higher levels of Education 4.0 competencies. Digital Professional Learning ($\beta = .109$, $p = .023$), Self-Directed Technology Learning ($\beta = .115$, $p = .016$), and ICT Integration Practices ($\beta = .096$, $p = .047$) also contributed significantly, though with comparatively smaller effect sizes. These findings extend the bivariate correlation result and indicate that collaborative and reflective dimensions of technology-enabled professional development carry the greatest predictive weight for Education 4.0 skill development among preservice teachers.

Difference Based on Gender (H_{02} and H_{03})

The findings of the independent samples t-test looking at gender differences are shown in Table 6.

Table 6

Independent Samples t-Test: Difference in TEPDPS and E4SS Based on Gender

Scale	Group	N	M	SD	t-value	df	p-value	Decision
TEPDPS	Male	161	93.52	9.34				
	Female	232	93.75	9.30	-0.250	391	.803	H_{02} Retained
E4SS	Male	161	133.16	13.21				
	Female	232	134.68	12.21	-1.173	391	.241	H_{03} Retained

Male and female did not vary statistically significantly according to the independent samples t-test preservice teachers on either the TEPDPS ($t = -0.250$, $df = 391$, $p = .803$) or the E4SS ($t = -1.173$, $df = 391$, $p = .241$). While female preservice teachers obtained marginally higher mean scores on both scales, The traditional criterion of statistical significance ($p < .05$) was not met by these changes. Consequently, null hypotheses H_{02} and H_{03} were retained. These findings suggest that gender does not constitute a significant differential factor in either technology-enabled

professional development practices or Education 4.0 skill levels among preservice teachers in the current sample.

Difference Based on Type of Institution (H_{04})

The findings of the one-way ANOVA looking at variations according to institution type are shown in Table 7.

Table 7

One-Way ANOVA: Difference in TEPDPS and E4SS Based on Type of Institution

Scale	Institution Type	N	M	SD	F-value	p-value	Decision
TEPDPS	Government	102	93.25	9.57			
	Government Aided	133	94.17	9.45	0.283	.754	H_{04} Retained
	Private	165	93.75	9.01			
E4SS	Government	102	133.25	11.73			
	Government Aided	133	134.85	12.95	0.465	.629	H_{04} Retained
	Private	165	134.24	12.81			

Note. df between groups = 2; df within groups = 397. Significance level: $p < .05$.

TEPDPS scores did not differ statistically significantly, according to a one-way ANOVA ($F = 0.283$, $p = .754$) or E4SS scores ($F = 0.465$, $p = .629$) based on type of institution. Although government-aided institution students recorded marginally higher mean scores on the E4SS ($M = 134.85$), the between-group variance was not significant. Both null hypotheses H_{04} were therefore retained. This finding suggests that the type of institution attended does not differentially influence either technology-enabled professional development engagement or the development of Education 4.0 skills among preservice teachers in this sample.

Difference Based on Locality of Institution (H_{05})

Table 8 presents the results of the independent samples t-test examining locality differences.

Table 8

Independent Samples t-Test: Difference in TEPDPS and E4SS Based on Locality of Institution

Scale	Locality	N	M	SD	t-value	df	p-value	Decision
TEPDPS	Rural	161	94.51	9.10				
	Urban	239	93.26	9.39	1.326	398	.186	H_{05} Retained
E4SS	Rural	161	135.52	12.24				
	Urban	239	133.30	12.75	1.739	398	.083	H_{05} Retained

Note. df = degrees of freedom. Significance level: $p < .05$.

Preservice teachers from rural and urban institutions did not significantly vary in their TEPDPS results, according to the independent samples t-test ($t = 1.326$, $df = 398$, $p = .186$) or E4SS scores ($t = 1.739$, $df = 398$, $p = .083$). Mean scores on both scales were comparable across locality groups. Both null hypotheses H_{05} were therefore retained. Given past presumptions on the digital gap between rural and urban educational settings, this discovery is significant; the present results suggest that in the current sample, locality of institution does not constitute a meaningful differentiating factor in terms of professional development engagement or Education 4.0 skill levels.

Major findings

Preservice teachers demonstrated a moderate to above-average level of technology-enabled professional development practices ($M = 93.76$, $SD = 9.28$), with Self-Directed Technology

Learning recording the highest dimension mean (M = 3.81). Preservice teachers demonstrated a moderate to above-average level of Education 4.0 skills (M = 134.19, SD = 12.58), with balanced performance across all seven dimensions (range: M = 3.80 to M = 3.87). Education 4.0 skills and technology-enabled professional development methods were shown to be significantly positively moderately correlated ($r = 0.490$, $p < .001$), indicating that greater engagement with technology-enabled professional development is associated with higher Education 4.0 skill levels. H_{01} was rejected. Gender-based differences in technology-enabled professional development practices were not statistically significant ($t = -0.250$, $p = .803$). H_{02} was retained. Gender-based differences in Education 4.0 skills were not statistically significant ($t = -1.173$, $p = .241$). H_{03} was retained. No statistically significant difference was found in technology-enabled professional development practices ($F = 0.283$, $p = .754$) or Education 4.0 skills ($F = 0.465$, $p = .629$) based on the institutional category. H_{04} was retained. Technology-enabled professional development practices did not vary statistically significantly ($t = 1.326$, $p = .186$) or Education 4.0 skills ($t = 1.739$, $p = .083$) based on the locality of the institution. H_{05} was retained.

Discussion

The goal of the current study was to ascertain the kind and strength of the association between these two variables as well as the degree of technology-enabled professional development practices and Education 4.0 competencies among preservice teachers (Das & J.V., 2026). The discovery that preservice teachers exhibited above-average levels of technology-enabled professional development practices aligns with the findings of (Hou et al., 2022), who noted an increase in Indian preservice teachers' involvement in online professional learning communities after the COVID-19 pandemic. The high Self-Directed Technology Learning dimension score indicates that a large number of preservice teachers are individually investigating digital learning options to enhance their professional expertise. This finding also reflects the growing importance of self-directed learning in Education 4.0 environments (Devi et al., 2026). The above-average levels of Education 4.0 skills observed in this sample are broadly consonant with (Siyam et al., 2025) The discovery that consistent use of technology in teacher preparation leads to quantifiable gains in digital proficiency. The uniform distribution of scores across all seven dimensions suggests that preservice teacher education programmes are broadly developing the full spectrum of Education 4.0 competencies, without notable gaps in any specific area (Momdjian et al., 2025). The most theoretically significant finding is the moderate positive correlation between technology-enabled professional development practices and Education 4.0 skills ($r = 0.490$, $p < .001$). This corroborates the positions of that deliberate engagement with digitally mediated professional development experiences contributes meaningfully to the development of twenty-first century and Education 4.0 competencies(Busnawir et al., 2025). The absence of significant gender differences on both scales is consistent with several recent studies in the Indian context (Bipasha et al., 2025) and may reflect the increasing equalisation of access to digital technologies and online learning resources across gender groups. This finding may partly reflect the expanded reach of mobile internet infrastructure in rural India over the past decade and the widespread use of smartphones as learning devices among student teachers (Enciso-Huamani et al., 2025)

Educational implications

Teacher education institutions should systematically embed technology-enabled professional learning activities, including online workshops, LMS-mediated collaborative learning, and reflective digital practices within the formal curriculum, rather than treating them as supplementary enrichment activities. Since the study found a positive relationship between technology-enabled professional development and Education 4.0 skills, teacher educators should

encourage the regular use of technology-supported professional learning activities within pedagogy courses. Policymakers may consider mandating a minimum quantum of technology-enabled professional development activities within teacher education programme frameworks, with appropriate monitoring and assessment mechanisms.

Limitations of the study

The study employed self-report Likert-scale measures, which are subject to social desirability bias, response set bias, and common method variance. However, the single-factor test by Harman showed that the first unrotated factor explained only 9.09% of total variance, which is far below the 50% level, indicating that common method bias does not dominate the present findings (Podsakoff et al., 2003). Objective performance-based assessments of Education 4.0 skills would provide a more robust measure of actual competency. The cross-sectional survey design precludes causal inferences. The observed correlation between technology-enabled professional development practices and Education 4.0 skills cannot be interpreted as evidence of a causal relationship without longitudinal or experimental verification. The sample was collected through purposive convenience sampling via a Google Form, rather than probability-based random sampling. This limits the generalizability of the findings to the broader population of preservice teachers in India. Future studies should attempt stratified random sampling from a defined institutional sampling frame.

Suggestions for future research

Future studies may examine how Education 4.0 skills develop over time through longitudinal research designs involving technology-enabled professional development programmes. Experimental and quasi-experimental studies can also be conducted to better understand the impact of specific technology-supported professional development activities on the development of Education 4.0 competencies among preservice teachers. Further research may compare preservice teachers from different states, universities, or teacher education curricula to identify possible contextual differences in technology-enabled professional development practices and Education 4.0 skills.

Conclusion

The present study explored the relationship between technology-enabled professional development practices and Education 4.0 skills among preservice teachers in India using a descriptive correlational survey with 400 participants. The findings showed a moderate positive relationship between the two variables ($r = 0.490$, $p < .001$), indicating that preservice teachers who engaged more in technology-supported professional development activities also reported stronger Education 4.0 skills.The study further found that preservice teachers demonstrated moderate to above-average levels in both technology-enabled professional development practices and Education 4.0 competencies. No significant differences were observed based on gender, type of institution, or locality of institution. These findings suggest that technology-supported professional learning should be given greater importance within teacher education programmes. As digital technologies continue to influence educational practices in India, teacher education institutions need to provide preservice teachers with meaningful opportunities to develop digital and professional competencies required in Education 4.0 environments.

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