I.J. Modern Education and Computer Science, **2026, 5, 104-117**
Published Online on October 8, 2026 by MECS Press (http://www.mecs-press.org/)
DOI: 10.5815/ijmecs.2026.05.06

Reflective Culture and Digital Competence in Pre-Service Teacher Development: The Mediating Role of Instructional Smart Self-Efficacy

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Received: February 10, 2026; Revised: May 12, 2026; Accepted: July 12, 2026; Published: October 8, 2026

Abstract: Teacher education requires models that connect reflective practice and digital competence with the psychological processes through which professional growth occurs. This longitudinal pre-test/post-test quasi-experiment examined whether a composite reflective-digital practice process predicted professional development and whether instructional smart self-efficacy mediated this association. The sample comprised 120 third-year pre-service teachers enrolled in a Computer Science Pedagogy program (N = 120) who completed a 15-week intervention organized across four instructional conditions. Data were collected with an expert-reviewed 19-item questionnaire using a five-point Likert scale. Confirmatory factor analysis and structural equation modeling were used to assess the measurement and structural models, and indirect effects were evaluated with 5,000 bias-corrected bootstrap resamples. Internal consistency was satisfactory across the four constructs (Cronbach's alpha = 0.86-0.91). Reflective-digital practice was positively associated with professional outcomes (beta = 0.41, $p < 0.001$), whereas its path to instructional smart self-efficacy (beta = 0.12, $p = 0.184$) and the direct path from self-efficacy to professional outcomes (beta = 0.10, $p = 0.211$) were not significant. The bootstrapped indirect estimate was significant (B = 0.09, 95% CI [0.02, 0.17], $p = 0.018$), and the model explained 54% of the variance in professional outcomes ($R^2 = 0.54$). These findings provide preliminary empirical support for a mediated reflective-digital pathway, while the single-program sample and reliance on self-reports limit causal and population-level inference.

Index Terms: Reflective Culture, Digital Competence, Pre-Service Teacher Development, Instructional Smart Self-Efficacy, Longitudinal Quasi-Experiment, Structural Equation Modeling.

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1. Introduction

Digital transformation has changed what teachers are expected to know and how teacher education supports professional growth. Digital competence training can shape professional learning and instructional activity [1], while contemporary frameworks increasingly define competence as the pedagogically informed use of technology rather than technical operation alone [2]. Pre-service teachers nevertheless report uneven preparation for applying digital knowledge in authentic instructional contexts [3].

This gap is especially relevant in computer science teacher education, where future teachers must connect subject knowledge, digital tools, and pedagogical decisions. Institutional leadership and teacher competence are associated with students' digital citizenship [4], and targeted professional upskilling can improve teachers' digital competence [5]. At the same time, organizational and infrastructural barriers can prevent new competence from becoming sustained instructional practice [6].

Reflective culture offers a mechanism for converting experience, feedback, and instructional difficulty into professional learning. Reflection can be embedded in organizational learning [7], and professional dialogue can make digital competence more visible and open to development [8]. Peer-assisted and immersive learning activities illustrate how competence can be strengthened through situated participation [9], while recent work with pre-service teachers emphasizes the need to adapt development strategies to learners and contexts rather than apply one uniform model [10].

Two benchmark frameworks clarify the remaining gap. Technological Pedagogical Content Knowledge (TPACK) explains the knowledge domains required for technology-integrated teaching [11], and DigCompEdu specifies professional, pedagogical, and learner-oriented areas of educator digital competence [12]. Both frameworks are valuable for defining competence, but neither by itself specifies or tests a temporal pathway in which reflective culture and digital competence influence professional development through instructional smart self-efficacy. Recent studies also rely heavily on cross-sectional self-reports, leaving the temporal ordering and psychological mechanism of development underexamined.

This study addresses that gap through four contributions. First, it evaluates a 15-week pre-test/post-test quasi-experiment with 120 third-year pre-service computer science teachers. Second, it represents reflective culture and digital competence as a combined reflective-digital practice predictor while retaining their distinct measurement dimensions. Third, it tests the direct and bootstrapped indirect pathways through instructional smart self-efficacy. Fourth, it reports the complete 19-item instrument, measurement-quality criteria, structural equations, and replication syntax needed to reconstruct the analytical model.

2. Related Works

Research on digitally mediated teacher development spans reflective practice, digital competence, self-efficacy, and professional outcomes, but these strands are often studied independently. The following review therefore distinguishes the contribution of each strand and identifies the untested pathway that motivates the present longitudinal model.

2.1. Reflective Culture in Teacher Professional Development

Reflective practice is grounded in the distinction between reflection in action and reflection on action [13]. Teacher learning also includes cognitive, emotional, motivational, and contextual processes that conventional professional development may not capture [14]. Recent work links teacher digital competence development to motivation and institutional culture [15], while school-level digital transformation studies show that organizational capacity affects whether technology changes pedagogy [16]. Teachers' responses to change also vary across career and emotional contexts [17], and digitally delivered professional development can expand access without guaranteeing transfer to practice [18]. These studies establish reflection as a developmental process but rarely test it jointly with digital competence and a psychological mediator over time.

2.2. Digital Competence in Computer Science and Technology Education

Digital competence is multidimensional. DigCompEdu-based research with pre-service teachers identifies pedagogical, professional, and technical components [19], and studies of higher education academics show that competence can differ substantially across these areas [20]. Adaptive tutoring systems further require teachers to make pedagogical decisions about data, feedback, and learner support rather than merely operate software [21]. Reviews of higher education confirm wide variation in definitions and measures [22], while comparative studies report contextual differences across educational stages and socio-digital environments [23]. Perception-based lifelong-learning measures remain common [24]. Consequently, existing evidence maps competence well but provides less evidence about how competence combines with reflection to produce professional outcomes.

2.3. Instructional Smart Self-Efficacy and Technology-Based Teaching

Technology-related self-efficacy is associated with acceptance, motivation, and self-directed learning [25]. Digital competence needs can also differ across participant groups [26], and institutional digital leadership, teacher competence, and technology behavior are structurally related [27]. Bibliometric reviews nevertheless show that educational digital-competence research remains dispersed across constructs and contexts [28]. Adaptive professional-development models therefore argue against uniform interventions [29], while knowledge mapping studies call for stronger integration of psychological and pedagogical variables [30]. These findings justify examining instructional smart self-efficacy as a mediator, but they do not establish that self-efficacy must exert a significant direct effect on professional outcomes.

2.4. Integrated Models and the Remaining Research Gap

Integrated frameworks have begun to broaden the field. HeDiCom organizes higher education teachers' digital competencies around professional learning, educational innovation, and collaboration [31], and teacher digital competence has been linked to technology acceptance [32]. Recent synthesis also emphasizes the continuing need to connect pedagogy, digital skills, and professional development [33]. Learning analytics can supply behavioral evidence beyond self-report [34], and online STEAM training illustrates one intervention route [35]. Reviews of generative artificial intelligence and teacher development [36] and studies of teachers' artificial-intelligence competencies [37] further expand the competence domain. However, these models mainly define dimensions, describe readiness, or assess cross-sectional associations. A longitudinal pathway that combines reflective culture and digital competence and tests instructional smart self-efficacy as a mediator remains insufficiently examined.

3. Research Methodology

The methodology was organized as a longitudinal pre-test/post-test quasi-experiment with a 15-week reflective-digital intervention. The analytical workflow linked participant selection, four instructional conditions, an expert-reviewed 19-item instrument, measurement-model assessment, structural equation modeling (SEM), and bias-corrected mediation analysis. This structure separates the intervention design from the post-intervention structural associations and provides a reproducible account of how the reported coefficients were obtained.

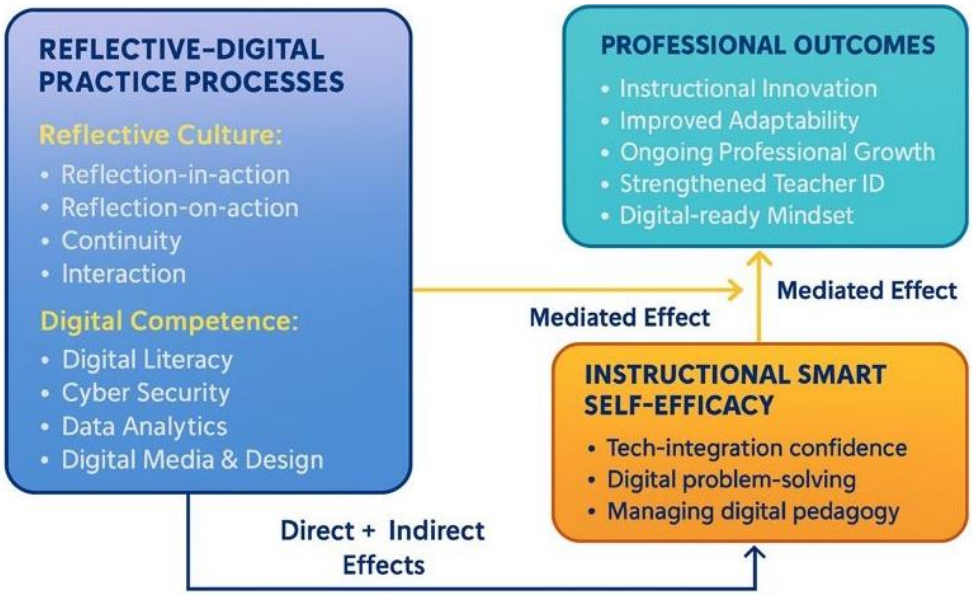


Fig. 1. Operational Model of the Reflective-Digital Development Pathway and Measured Dimensions.

Figure 1 presents the operational model used in the study. Reflective culture and digital competence are measured as distinct subscales and combined into the reflective-digital practice (RDP) predictor. Instructional smart self-efficacy (ISSE) is the mediator, and professional outcomes (PO) form the endogenous construct. The model therefore estimates the direct RDP-to-PO path, the RDP-to-ISSE and ISSE-to-PO paths, and the indirect effect through ISSE.

3.1. Research Design and Analytical Strategy

The study used a longitudinal quasi-experimental design because participants were recruited from one intact Computer Science Pedagogy program rather than from a population-level sampling frame. Within the recruited cohort, gender stratification and randomized allocation were used to distribute participants across four instructional conditions.

Measurements were administered before and after the intervention, establishing the temporal order of exposure and outcome assessment without supporting unrestricted causal generalization.

The analysis proceeded in five stages: complete-case screening and scale scoring; reliability and confirmatory factor analysis; inspection of baseline comparability; estimation of the post-intervention structural paths; and bias-corrected bootstrap estimation of the indirect effect. Group conditions defined exposure, whereas the SEM used continuous post-intervention construct scores. The study did not treat group labels as latent variables.

The intervention lasted one 15-week semester, with three scheduled hours per week and approximately 45 hours of total exposure. Reflective activities included structured review of instructional decisions and peer feedback. Digital activities involved the use, adaptation, and evaluation of educational technologies within program-based instructional tasks. The integrated condition combined both components; the remaining conditions isolated or minimized them.

Baseline measures covered reflective culture, digital competence, instructional smart self-efficacy, and professional outcomes. Post-test measures used the same constructs. Because the sample comprised pre-service teachers, references to instructional practice concern coursework, simulated teaching, or other program-based teaching activities rather than verified in-service classroom performance.

The structural model followed standard SEM and mediation notation [38, 39]. For participant i, M denotes ISSE, Y denotes professional outcomes, and RDP denotes the composite reflective-digital predictor. Equations (1)-(4) define the measurement covariance structure, mediator equation, outcome equation, indirect effect, and total effect. Direct structural coefficients are reported as standardized beta values; the bootstrapped indirect effect is reported as an unstandardized estimate B.

$$\Sigma(\theta) = \Lambda\Phi\Lambda' + \Theta\varepsilon \tag{1}$$

$$M_{\mathrm{i}} = \alpha M + aRDP_{\mathrm{i}} + \varepsilon M_{\mathrm{i}} \tag{2}$$

$$Y_{\mathrm{i}} = \alpha Y + c'RDP_{\mathrm{i}} + bM_{\mathrm{i}} + \varepsilon Y_{\mathrm{i}} \tag{3}$$

$$IE = ab,\ \ TE = c' + ab \tag{4}$$

3.2. Operationalization of Constructs

The instrument contained 19 positively keyed items scored from 1 (strongly disagree) to 5 (strongly agree). Items were reviewed by specialists in educational technology and teacher development for clarity and content coverage.

- Reflective culture was measured with five items addressing reflection during and after instructional activity, continuity of reflection, use of feedback, and professional dialogue.
- Digital competence was measured with five items addressing educational-software use, cybersecurity, use of digital data, design or adaptation of digital materials, and pedagogical integration of digital tools.
- Instructional smart self-efficacy was measured with four items concerning confidence in technology integration, digital problem solving, management of digital teaching environments, and adaptation when tools fail.
- Professional outcomes were measured with five items covering instructional innovation, adaptability, continuing professional learning, professional identity, and readiness for future digitally mediated teaching demands.

Each subscale score was computed as the mean of its completed items. The RDP predictor was formed as the mean of the standardized reflective-culture and digital-competence subscale scores, preserving equal contribution from the two dimensions. Higher scores indicate more frequent or more confident endorsement of the measured construct.

3.3. Research Hypotheses

Four directional hypotheses were specified before structural interpretation. Statistical support required $p < 0.05$ for direct paths or a 95% bootstrap confidence interval that excluded zero for the indirect path.

H1: Reflective-digital practice is positively associated with professional outcomes.

H2: Reflective-digital practice is positively associated with instructional smart self-efficacy.

H3: Instructional smart self-efficacy is positively associated with professional outcomes.

H4: Instructional smart self-efficacy mediates the association between reflective-digital practice and professional outcomes.

The hypotheses concern the reported composite RDP pathway. A separate digital-competence-to-outcome coefficient was not available in the study record and is therefore not claimed or tested as an additional hypothesis.

3.4. Participants and Intervention

The sample comprised 120 third-year pre-service teachers enrolled in a Computer Science Pedagogy program. The cohort included 60 men and 60 women. Gender-stratified selection was followed by allocation within the recruited cohort to reduce demographic imbalance across the four instructional conditions. The unit of analysis was the individual participant.

The intervention was delivered for one 15-week semester at three hours per week. The four conditions represented low or high emphasis on structured reflection and low or high emphasis on digital integration. Table 1 summarizes the verified participant and protocol characteristics.

Table 1. Participant Characteristics and Intervention Parameters.

Category	Description
Population	Third-year pre-service teachers enrolled in the Computer Science Pedagogy program
Total Sample Size (N)	120 participants
Gender Distribution	60 men (50%) and 60 women (50%)
Sampling Method	Gender-stratified selection with allocation within the recruited cohort
Academic Level	Undergraduate, Year 3
Institutional Context	Higher education program in Computer Science Pedagogy
Intervention Duration	One semester (15 weeks)
Weekly Intervention Time	3 hours per week
Total Exposure Time	Approximately 45 hours (15 weeks × 3 hours)
Study Design Type	Longitudinal pre-test/post-test quasi-experiment

3.5. Data Collection and Processing

The questionnaire was administered electronically at pre-test and post-test under consistent instructions. Participants received information about the study purpose, voluntary participation, confidentiality, and the right to withdraw. Table 2 presents the complete item set and response format. Because the participants were pre-service teachers, the wording was interpreted in relation to coursework and program-based instructional activities.

Table 2. Questionnaire Items for Reflective-Digital Practice, Instructional Smart Self-Efficacy, and Professional Outcomes.

Construct	Code	Item Statement	Measurement Scale
Reflective Culture	RC1	I regularly reflect on my instructional practice during coursework or teaching activities.	5-point Likert (1 = Strongly Disagree, 5 = Strongly Agree)
	RC2	After completing an instructional activity, I critically evaluate its effectiveness for future improvement.	5-point Likert
	RC3	I use feedback from peers, instructors, or students to refine my instructional approach.	5-point Likert
	RC4	Reflection is a continuous part of my professional learning routine.	5-point Likert
	RC5	I engage in professional dialogue with peers to reflect on instructional challenges.	5-point Likert
Digital Competence	DC1	I am confident in using digital devices and educational software for instructional purposes.	5-point Likert
	DC2	I apply appropriate cybersecurity practices when using digital technologies in teaching.	5-point Likert
	DC3	I use digital data (e.g., learning analytics, assessments) to inform instructional decisions.	5-point Likert
	DC4	I am capable of designing or adapting digital learning materials to support instruction.	5-point Likert
	DC5	I effectively integrate digital tools to enhance student engagement and learning outcomes.	5-point Likert
Instructional Smart Self-Efficacy	ISSE1	I feel confident integrating digital technologies into my instructional practices.	5-point Likert
	ISSE2	I can effectively solve instructional problems that arise from digital technology use.	5-point Likert
	ISSE3	I am capable of managing digital teaching environments efficiently.	5-point Likert
	ISSE4	I remain confident in adapting my teaching strategies when digital tools do not function as expected.	5-point Likert
Professional Outcomes	PO1	I use innovative instructional strategies in coursework or teaching activities.	5-point Likert

Construct	Code	Item Statement	Measurement Scale
	PO2	I am adaptable when teaching conditions or technologies change.	5-point Likert
	PO3	I actively pursue opportunities for continuous professional development.	5-point Likert
	PO4	My professional identity has strengthened through the use of digital teaching practices.	5-point Likert
	PO5	I feel prepared to meet future teaching demands in digitally mediated environments.	5-point Likert

Only fully completed questionnaires were retained, so no missing-value imputation was applied. All items used the same 1-5 direction and required no reverse scoring. Responses were checked against the permitted scale range, and subscale means were calculated only after complete-case screening. The fixed analytic sample was N = 120. The bootstrap procedure used 5,000 resamples.

3.6. Measurement and Structural Model Assessment

The measurement model related the observed item vector to the latent constructs through the loading matrix. Equation (1) expresses the model-implied covariance matrix, where Lambda contains factor loadings, Phi contains latent covariances, and Theta-epsilon contains residual variances. Latent scales were identified by fixing one loading per factor to 1.0. No residual covariance was introduced solely to improve fit.

Internal consistency was evaluated with Cronbach's alpha and composite reliability (CR). As shown in Table 3, alpha ranged from 0.86 to 0.91 and CR ranged from 0.89 to 0.93, exceeding the 0.70 criterion for all constructs.

Convergent validity was evaluated through standardized factor loadings and average variance extracted (AVE). All reported loadings exceeded 0.65 ($p < 0.001$), and AVE ranged from 0.59 to 0.71, above the 0.50 criterion.

Table 3. Reliability and Convergent Validity Results.

Construct	Cronbach's Alpha	Composite Reliability (CR)	AVE
Reflective Culture	0.88	0.91	0.64
Digital Competence	0.90	0.92	0.67
Instructional Smart Self-Efficacy	0.86	0.89	0.59
Professional Outcomes	0.91	0.93	0.71

Discriminant validity was assessed with the Fornell-Larcker criterion [40]. In Table 4, the square root of each construct's AVE on the diagonal exceeds its correlations with the other constructs. This pattern supports empirical separation among reflective culture, digital competence, instructional smart self-efficacy, and professional outcomes.

Table 4. Discriminant Validity (Fornell–Larcker Criterion).

Construct	RC	DC	ISSE	PO
Reflective Culture (RC)	**0.80**	0.52	0.48	0.56
Digital Competence (DC)	0.52	**0.82**	0.45	0.60
Instructional Smart Self-Efficacy (ISSE)	0.48	0.45	**0.77**	0.41
Professional Outcomes (PO)	0.56	0.60	0.41	**0.84**

Confirmatory factor analysis was evaluated before structural-path interpretation. Table 5 reports chi-square/df = 2.14, CFI = 0.93, TLI = 0.92, RMSEA = 0.061, and SRMR = 0.048. Taken together, these indices indicate acceptable measurement-model fit under the stated thresholds.

Table 5. Confirmatory Factor Analysis Model Fit Indices.

Fit Index	Value	Recommended Threshold	Interpretation
χ^2/df	2.14	< 3.00	Acceptable
CFI	0.93	> 0.90	Good
TLI	0.92	> 0.90	Good
RMSEA	0.061	< 0.08	Acceptable
SRMR	0.048	< 0.08	Good

The measurement results support interpretation of the structural paths, but they do not establish causal validity. Structural coefficients, R-squared, local effect sizes, and the bootstrap interval were therefore interpreted together and within the limits of the quasi-experimental design.

3.7. Common Method Bias and Reproducibility

Because all focal constructs were self-reported, procedural safeguards and post hoc diagnostics were used [41]. Anonymity, neutral wording, randomized item order, and separation of predictor and outcome blocks were intended to reduce evaluation apprehension and consistency responding. Harman's single-factor test and full-collinearity variance inflation factors were used as diagnostics rather than as proof that common method bias was absent.

Table 6. Common Method Bias Diagnostic Results.

Test / Indicator	Procedure Applied	Result	Threshold	Interpretation
Harman's Single-Factor Test	Unrotated exploratory factor analysis including all measurement items	First factor explained 32.4% of total variance	< 50%	No dominant single factor detected
Number of Factors with Eigenvalue > 1	Exploratory factor extraction	4 factors identified	> 1 expected	Multidimensional structure confirmed
Full Collinearity VIF (Minimum)	SEM collinearity assessment	1.42	< 3.3	Acceptable
Full Collinearity VIF (Maximum)	SEM collinearity assessment	2.18	< 3.3	Acceptable
Mean VIF Value	SEM collinearity assessment	1.73	< 3.3	Low collinearity risk

As summarized in Table 6, the common method bias diagnostics indicated no substantial methodological concern. Harman's single-factor test showed that the first factor accounted for only 32.4% of the total variance, while the full collinearity VIF values ranged from 1.42 to 2.18, remaining below the threshold of 3.3. These results, together with the identification of four distinct factors, support the multidimensional structure of the measurement model and indicate a low risk of common method bias.

The first unrotated factor explained 32.4% of the variance, and full-collinearity VIF values ranged from 1.42 to 2.18. These results show no dominant single-factor pattern, although self-report bias remains possible. Table 2 supplies the full item wording [42]. Independent numerical reproduction still requires the deidentified participant-level data and the original allocation record.

4. Results of Pedagogical Experiments

The results are presented in the same order as the analytical workflow. Measurement quality is summarized first, followed by the intervention conditions and baseline reporting scope, the three direct structural paths, global model fit and effect sizes, the bootstrapped indirect effect, and the consolidated hypothesis decisions. This sequence links each inference to the evidence reported in the corresponding table.

4.1. Analytical Workflow and Reporting Scope

Complete cases were scored before the measurement and structural models were evaluated. Reliability, AVE, discriminant validity, and confirmatory fit were examined before any structural path was interpreted. The direct paths were then estimated, followed by global structural fit, explained variance, local effect sizes, and the 5,000-resample bias-corrected mediation test.

The reported structural results concern the post-intervention continuous scores. H1 was supported because the RDP-to-PO path was significant. H2 and H3 were not supported because the RDP-to-ISSE and ISSE-to-PO paths were not significant. H4 was supported because the bootstrap interval for the indirect estimate excluded zero. These decisions concern statistical associations within the fitted model and should not be read as unrestricted causal claims.

The next subsection describes how the four instructional conditions generated variation in reflective and digital exposure before the structural estimates are reported.

4.2. Experimental Conditions and Baseline Reporting

The quasi-experiment used four conditions: G1 combined low reflective emphasis with low digital integration; G2 emphasized reflection; G3 emphasized digital integration; and G4 combined both components. Table 7 defines the instructional contrast represented by each condition. Group membership was an exposure condition and was not treated as a latent SEM construct.

Baseline comparability was assessed with one-way analysis of variance. The retained study record reports only that all baseline tests yielded p-values above 0.05; it does not contain the construct-specific means, standard deviations, F statistics, or effect sizes requested for full reporting. No numerical values were reconstructed. Baseline equivalence is therefore treated as a design check, and the missing descriptive and inferential details remain a reporting limitation.

Table 7. Description of Experimental Groups and Pedagogical Conditions.

Group	Reflective Culture	Digital Competence	Description of Instructional Condition
G1 (Control)	Low	Low	Traditional instruction with minimal digital tool use and no structured reflection
G2 (Reflective)	High	Low	Structured reflective activities with limited digital integration
G3 (Digital)	Low	High	Intensive digital learning environment use without formal reflective practices
G4 (Integrated)	High	High	Combined reflective culture and advanced digital competence integration

The SEM used post-intervention RDP, ISSE, and PO values as continuous variables. A separate multi-group invariance test was not reported, so equivalence of structural parameters across the four conditions is not claimed. The reported paths instead describe associations in the pooled analytic sample.

With this distinction between intervention exposure and pooled structural estimation established, Sections 4.3-4.7 report the direct, fit, and mediation results.

4.3. Reflective-Digital Practice and Professional Outcomes

H1 tested whether reflective-digital practice was positively associated with professional outcomes. The structural path represents the combined contribution of standardized reflective-culture and digital-competence subscale scores rather than a separate coefficient for either component.

Table 8 reports the standardized coefficient, standard error, Wald statistic, p value, and hypothesis decision.

Table 8. Reflective-Digital Practice Path to Professional Outcomes.

No.	Structural Path	Standardized Coefficient (β)	Std. Error	z-value (Wald)	p-value	Decision
H1	Reflective-Digital Practice -> Professional Outcomes	0.41	0.07	5.86	< 0.001	Supported

The RDP-to-PO path was positive and statistically significant (beta = 0.41, SE = 0.07, z = 5.86, $p < 0.001$). The coefficient indicates a moderate positive association after accounting for the other paths in the model.

The estimate is consistent with the expected ordering of the instructional conditions, but group-specific post-test means and repeated-measures statistics were not available for verification. The coefficient therefore supports the modeled association rather than a quantified between-group treatment effect.

H1 was supported. This result provides evidence that the combined reflective-digital process is related to stronger professional-development perceptions in this cohort.

4.4. Reflective-Digital Practice and Instructional Smart Self-Efficacy

H2 tested whether reflective-digital practice was positively associated with instructional smart self-efficacy. The mediator represents confidence in technology integration, digital problem solving, management of digital teaching environments, and adaptation when tools do not function as expected.

Table 9 reports the direct structural path used to evaluate H2.

Table 9. Reflective-Digital Practice Path to Instructional Smart Self-Efficacy.

No.	Structural Path	Standardized Coefficient (β)	Std. Error	z-value (Wald)	p-value	Decision
H2	Reflective-Digital Practice -> Instructional Smart Self-Efficacy	0.12	0.09	1.33	0.184	Not supported

The path was positive but not statistically significant (beta = 0.12, SE = 0.09, z = 1.33, p = 0.184). The data therefore do not support a direct association at the 0.05 level.

This finding suggests that exposure to reflective and digital activities was not sufficient, by itself, to produce a clear shift in perceived instructional capability. Performance feedback, mastery experience, and longer follow-up may be needed before self-efficacy changes are detectable.

H2 was not supported. ISSE was nevertheless retained in the mediation test because an indirect effect is evaluated from the product of paths and its bootstrap distribution, not from the significance of either constituent path alone.

4.5. Instructional Smart Self-Efficacy and Professional Outcomes

H3 tested whether instructional smart self-efficacy was positively associated with professional outcomes after reflective-digital practice was included in the model. Table 10 reports the coefficient and inferential statistics for this path.

Table 10. Instructional Smart Self-Efficacy Path to Professional Outcomes.

No.	Structural Path	Standardized Coefficient (β)	Std. Error	z-value (Wald)	p-value	Decision
H3	Instructional Smart Self-Efficacy -> Professional Outcomes	0.10	0.08	1.25	0.211	Not supported

The ISSE-to-PO path was positive but not significant (beta = 0.10, SE = 0.08, z = 1.25, p = 0.211). H3 was therefore not supported. Perceived confidence alone did not explain a statistically distinguishable share of professional outcomes after the reflective-digital predictor was included. This result limits claims that self-efficacy is an independent driver of development in the present sample.

The non-significant direct path does not preclude an indirect process. Section 4.7 therefore evaluates the product of the RDP-to-ISSE and ISSE-to-PO paths with bootstrap confidence limits.

4.6. Structural Model Fit and Effect Sizes

After measurement-model assessment, global structural fit, explained variance, and local effect sizes were examined before the mediation result was interpreted.

Table 11 shows acceptable structural fit: chi-square/df = 2.18, CFI = 0.94, TLI = 0.93, RMSEA = 0.058, and SRMR = 0.046. These indices indicate that the specified covariance structure is compatible with the observed data under the reported thresholds.

Table 11. Structural Model Fit Indices.

Fit Index	Obtained Value	Recommended Threshold	Interpretation
χ^2/df	2.18	< 3.00	Acceptable
CFI	0.94	> 0.90	Good
TLI	0.93	> 0.90	Good
RMSEA	0.058	< 0.08	Acceptable
SRMR	0.046	< 0.08	Good

The model explained 54% of the variance in professional outcomes (R-squared = 0.54). The reported local effect size for reflective-digital practice was f-squared = 0.29, while the direct ISSE contribution was f-squared = 0.04 (Table 12).

The effect-size pattern is consistent with a stronger direct contribution from the reflective-digital predictor and a comparatively small direct contribution from instructional smart self-efficacy.

Table 12. Explained Variance and Structural Effect Sizes.

Metric	Value	Interpretation
Professional Outcomes R-squared	0.54	Substantial explained variance
Reflective-Digital Practice -> Professional Outcomes f-squared	0.29	Medium-large
Instructional Smart Self-Efficacy -> Professional Outcomes f-squared	0.04	Small

The fit and effect-size results support interpretation of the specified model within this sample. They do not resolve the missing group-level descriptive statistics or establish generalizability beyond the participating program.

4.7. Mediating Role of Instructional Smart Self-Efficacy

H4 was evaluated with 5,000 bias-corrected bootstrap resamples. This procedure estimated the sampling distribution of the indirect product ab without assuming normality. The direct path is reported as standardized beta, whereas the indirect result is reported as the unstandardized bootstrap estimate B.

Table 13 presents the direct, indirect, and total effects of reflective-digital practice processes (RDP) on professional outcomes (PO). The direct effect was significant (β = 0.41, 95% CI [0.27, 0.55], p < 0.001), while the indirect pathway through instructional smart self-efficacy (ISSE) was also significant (B = 0.09, 95% CI [0.02, 0.17], p = 0.018). The reported total effect was 0.50 (95% CI [0.36, 0.64], p < 0.001), indicating that RDP influenced professional outcomes through both direct and mediated pathways.

Table 13. Direct, Indirect, and Total Reflective-Digital Path Estimates.

Type	Path	Metric	Value	95% CI	p-value	Decision
Direct	RDP -> PO	Standardized beta	0.41	[0.27, 0.55]	< 0.001	Significant
Indirect	RDP -> ISSE -> PO	Unstandardized B	0.09	[0.02, 0.17]	0.018	Significant
Total	RDP -> PO	Reported total	0.50	[0.36, 0.64]	< 0.001	Significant

The indirect estimate was significant (B = 0.09, 95% CI [0.02, 0.17], p = 0.018) because the interval did not include zero. The direct path remained significant and positive (beta = 0.41, p < 0.001). The same-direction direct and indirect estimates are described as complementary mediation. H4 was supported, although the non-significant constituent paths and self-report design require cautious interpretation.

4.8. Consolidated Hypothesis Results

Table 14 consolidates the four pre-specified hypotheses and separates supported associations from paths that did not reach statistical significance. The decisions are based on the coefficients and bootstrap intervals.

Table 14. Consolidated Hypothesis Testing Results.

Hypothesis	Tested Path	Estimate	Statistical Evidence	Decision	Interpretation
H1	RDP -> PO	beta = 0.41	p < 0.001	Supported	Positive direct association
H2	RDP -> ISSE	beta = 0.12	p = 0.184	Not supported	Direct path not significant
H3	ISSE -> PO	beta = 0.10	p = 0.211	Not supported	Direct path not significant
H4	RDP -> ISSE -> PO	B = 0.09	95% CI [0.02, 0.17]; p = 0.018	Supported	Complementary mediation

The results support a direct RDP-to-PO association and a complementary indirect pathway through ISSE. They do not support either a direct RDP-to-ISSE path or a direct ISSE-to-PO path at p < 0.05. No separate direct effect of digital competence is reported because the required coefficient was absent from the verified results.

5. Discussion

The study provides preliminary empirical support for a reflective-digital pathway in pre-service teacher development. The strongest direct association linked the combined reflective-culture and digital-competence predictor to professional outcomes, while instructional smart self-efficacy contributed through a significant bootstrap indirect estimate but not through a significant direct path.

This pattern extends competence frameworks that describe what teachers should know by examining how reflective and digital dimensions operate together. It is compatible with recent evidence that teacher digital competence depends on motivational and institutional conditions [15] and with HeDiCom's emphasis on professional learning and educational innovation [31]. However, the present results concern self-reported development and should not be interpreted as observed classroom transformation.

The non-significant direct ISSE path also refines studies that connect self-efficacy, digital competence, and technology use. Self-efficacy may be more consequential when it is activated by structured practice and feedback than when it is treated as an isolated belief. The mediation estimate is consistent with this interpretation, but the non-significant constituent paths prevent a strong mechanistic claim.

For teacher-education programs, the practical implication is to integrate reflection with authentic digital design tasks. Guided lesson review, peer feedback, revision of digital materials, and evidence-based discussion of learner data may create stronger conditions for mastery experience than stand-alone technology workshops.

The limitations are substantial. The study used one program and self-reported measures, construct-level baseline means and repeated-measures statistics were unavailable, group sizes were not reported in the retained record, and multi-group invariance was not established. The analysis also lacks classroom observations, learning-platform logs, teaching artifacts, and longer-term follow-up. These constraints limit causal interpretation and external validity.

Future studies should preregister the analytical plan, retain the allocation record and fixed random seed, release deidentified data and executable syntax where permitted, and report group-level means, standard deviations, F statistics, corrected pairwise comparisons, and effect sizes. Replication across institutions, provinces, and disciplines would test whether the pathway remains stable under different teacher-education conditions.

6. Conclusion

This longitudinal quasi-experiment examined reflective culture, digital competence, instructional smart self-efficacy, and professional outcomes among 120 third-year pre-service computer science teachers. Reflective-digital practice was positively associated with professional outcomes (beta = 0.41, $p < 0.001$), and the model explained 54% of their variance. The direct paths from reflective-digital practice to instructional smart self-efficacy and from self-efficacy to professional outcomes were not significant. Nevertheless, the bootstrapped indirect estimate was significant (B = 0.09, 95% CI [0.02, 0.17]), providing preliminary empirical support for a complementary mediating role. The result does not constitute definitive validation of a causal framework because the study used one program, self-reported measures, and incomplete baseline reporting. Future work should combine validated questionnaires with classroom-observation scales, learning-management-system logs, assessed lesson plans, and digital teaching portfolios. Cross-provincial and cross-disciplinary samples, preregistered multi-group analyses, and follow-up measurements after teaching practice would clarify durability and generalizability. Within these limits, the findings support professional-development designs that connect structured reflection with purposeful digital practice and repeated opportunities to build instructional confidence.

All the Declarations and Statements

Author Contributions Statement

Aziz Shamitdinov – Conceptualization, methodology, and supervision; development of the theoretical framework and oversight of the study.
Ardak Rysbayeva – Intervention design and implementation; development of the reflective-digital instructional protocol.
Lyudmila Demchenko – Research design and data collection; coordination of participant involvement and data acquisition.
Aliya Kuralbayeva – Instrument development and validation; reliability and validity assessment.

All authors have read and agreed to the published version of the manuscript.

Conflict of Interest Statement

The authors declare no conflicts of interest.

Ethical Declarations

The study did not involve experiments on animals. Activities involving human participants followed applicable institutional and national ethical standards. Informed consent was obtained, participation was voluntary, and the questionnaire data were anonymized to protect confidentiality and privacy.

Acknowledgments

The authors thank the specialists who evaluated the instrument and provided recommendations on the intervention and reporting procedures.

Declaration of Generative AI in Scholarly Writing

During the preparation of this manuscript, generative AI tools were used solely to enhance language clarity, grammar, and overall readability. The technology was applied under full human oversight and control, and all generated text was carefully reviewed, edited, and verified by the authors to ensure accuracy, completeness, and academic integrity. No AI tools were used to generate research data, conduct statistical analyses, or draw scientific conclusions. Generative AI technologies are not listed as authors or co-authors. The authors take full responsibility for the content and integrity of this manuscript.

Abbreviations

The following abbreviations are used in this manuscript:

ANOVA – Analysis of Variance
AVE – Average Variance Extracted
CFA – Confirmatory Factor Analysis
CFI – Comparative Fit Index
CR – Composite Reliability
DC – Digital Competence

ISSE – Instructional Smart Self-Efficacy
PO – Professional Outcomes
RC – Reflective Culture
RDP – reflective-digital practice
RMSEA – Root Mean Square Error of Approximation
SEM – Structural Equation Modeling
SRMR – Standardized Root Mean Square Residual
TLI – Tucker-Lewis Index

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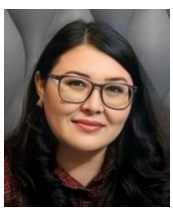
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How to cite this paper

Aziz Shamitdinov, Ardak Rysbayeva, Lyudmila Demchenko, Aliya Kuralbayeva, "Reflective Culture and Digital Competence in Pre-Service Teacher Development: The Mediating Role of Instructional Smart Self-Efficacy", International Journal of Modern Education and Computer Science(IJMECS), Vol.18, No.5, pp. 104-117, 2026. DOI:10.5815/ijmecs.2026.05.06