

---

# Toward Sustainable Digital Equity in Greek Primary Schools: Teacher Self-Efficacy, Student Engagement, and Bundled Professional Development Policies

---

[Georgios Polydoros](#)\*, [Christos Zisis](#), [Ilias Vasileiou](#), [Alexandros-Stamatios Antoniou](#), [Charis Polydoros](#)

Posted Date: 31 March 2026

doi: 10.20944/preprints202603.2359.v1

Keywords: digital equity; sustainability; teacher self-efficacy; student engagement; professional development; primary education; information systems



Preprints.org is a free multidisciplinary platform providing preprint service that is dedicated to making early versions of research outputs permanently available and citable. Preprints posted at Preprints.org appear in Web of Science, Crossref, Google Scholar, Scilit, Europe PMC.

Copyright: This open access article is published under a [Creative Commons CC BY 4.0 license](#), which permit the free download, distribution, and reuse, provided that the author and preprint are cited in any reuse.

Disclaimer/Publisher's Note: The statements, opinions, and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions, or products referred to in the content.

Article

# Toward Sustainable Digital Equity in Greek Primary Schools: Teacher Self-Efficacy, Student Engagement, and Bundled Professional Development Policies

Georgios Polydoros \*, Christos Zisis, Ilias Vasileiou, Alexandros-Stamatios Antoniou and Charis Polydoros

Université d' Angers; National and Kapodistrian University of Athens

\* Correspondence: georgiospolydoros@uoc.gr

## Abstract

This study examined how digital equity conditions and bundled professional development policies are associated with sustainable teacher learning, self-efficacy, and student engagement in Greek primary schools. A total of 460 in-service teachers from urban, suburban, and rural areas participated in the study. Data were collected through Likert-scale measures assessing information systems use, TPACK-aligned professional development outcomes, teacher self-efficacy, implementation challenges, and student engagement. The analysis included ANOVA, MANOVA, OLS regression with interaction terms, and mediation models. The findings indicated that infrastructure funding alone was not a significant predictor of teacher capacity or student engagement after the introduction of relevant controls. More consistent effects emerged when funding was combined with mandated and time-protected professional development, together with minimum connectivity standards. Teacher self-efficacy partially mediated the association between information systems use and student engagement, while stronger indirect effects were observed among early-career teachers. In addition, a bundled governance index was associated with a reduction in urban–rural disparities in teacher capacity. The findings suggest that sustainable digital equity in primary education depends not only on access to resources but also on coherent professional support structures that strengthen teacher confidence, instructional continuity, and long-term engagement. Implications are discussed for the design of sustainable professional development policies in teacher education and primary schooling.

**Keywords:** digital equity; sustainability; teacher self-efficacy; student engagement; professional development; primary education; information systems

---

## 1. Introduction

Digital transformation in schools has reshaped not only classroom practices but also the ways in which teachers learn, are mentored, and engage in professional development. In many education systems, post-COVID investments in devices, platforms, and connectivity were rapidly followed by large-scale initiatives in digital teacher professional development (TPD). Yet evidence from teacher education suggests that access to tools alone is insufficient when professional learning remains fragmented, voluntary, or weakly connected to classroom practice. For providers of preservice and in-service teacher education, the central question is no longer whether teachers use digital technologies, but under which governance and professional learning conditions such tools translate into sustained pedagogical change and more sustainable forms of digital equity.

In Greece, as elsewhere, substantial post-COVID investments in educational technology have not eliminated uneven digital capacity or variable teacher uptake across urban, suburban, and rural primary schools. Prior research has shown that teachers' motivation, beliefs, and self-efficacy are central to technology use (Backfisch et al., 2021; Gebhardt et al., 2019; Georgiou et al., 2023), yet intention alone rarely translates into meaningful integration without enabling conditions such as

reliable infrastructure, targeted TPD, and institutional support (UNESCO, 2023). The pandemic amplified both the potential and the constraints of information systems (IS): schools and teacher educators adopted digital platforms for learning, communication, assessment, and data management while simultaneously confronting anxiety, skills gaps, and unequal access (Azubuike et al., 2021; Guangul et al., 2020; Lebeničnik & Istenič Starčič, 2020; Talidong & Toquero, 2020; Saad et al., 2024; van Dijk, 2017).

In the present study, IS is defined broadly to include learning management systems (LMS), student information systems (SIS), assessment platforms, collaboration tools, and digital content environments. The focus is on how these systems reconfigure professional practice through collaboration, feedback, and adaptive instruction when supported by coherent policy and professional learning instruments. From a teacher education perspective, such systems become part of the learning environment through which teachers experience modeled digital pedagogy, receive feedback, and participate in communities of practice. Evidence from and beyond the COVID period indicates that digital environments can strengthen teacher capacity and agency, but such effects depend on systemic supports including training, monitoring, and resource adequacy (Eradze et al., 2023; Perry, 2023; Yang et al., 2024). These conditions are especially salient in rural schools, where infrastructure and PD opportunities often lag behind those in urban settings (Mustafa et al., 2024; Singh et al., 2021; Ventista et al., 2024a, 2024b).

Within the Greek primary education context, the implementation of educational IS is shaped by three core governance instruments: (a) resource allocation rules for devices and connectivity, including targeted grants and pooled procurement; (b) minimum service standards, such as device-to-student ratios, bandwidth thresholds, and platform availability, monitored by regional directorates; and (c) mandated TPD in digital pedagogy and assessment linked to classroom IS use. Together, these instruments define how schools and teacher professional learning are governed through funding formulas, standards and audits, and capacity-building requirements. For teacher education providers and school leaders, this policy bundle shapes the conditions under which digital TPD can be protected within school timetables, aligned with curricular expectations, and supported by adequate infrastructure.

Anchored in the governance of compulsory schooling, the present study treats IS funding, mandated and time-protected TPD, and minimum connectivity standards as policy instruments that structure digital teacher learning. The analysis focuses on in-service primary teachers as learners within a broader professional development system and asks when such policy levers enable them to build the TPACK necessary for technology-enhanced pedagogy. Gains in engagement are expected to emerge most clearly when funding is tied to accredited TPD and enforceable service standards. In addition, bundled governance arrangements combined with monitoring are expected to reduce rural–urban disparities by strengthening teacher self-efficacy. The study therefore speaks both to education policymakers and to teacher educators responsible for designing digital professional development architectures.

Accordingly, the study addresses four research questions concerning the relationship between governance instruments and teacher education outcomes in Greek primary schools:

**RQ1.** What are the effects of the three governance levers—(a) infrastructure funding, (b) mandated and time-protected TPD, and (c) minimum connectivity/service standards—on teacher capacity (skills enhancement and collaboration) across urban, suburban, and rural schools?

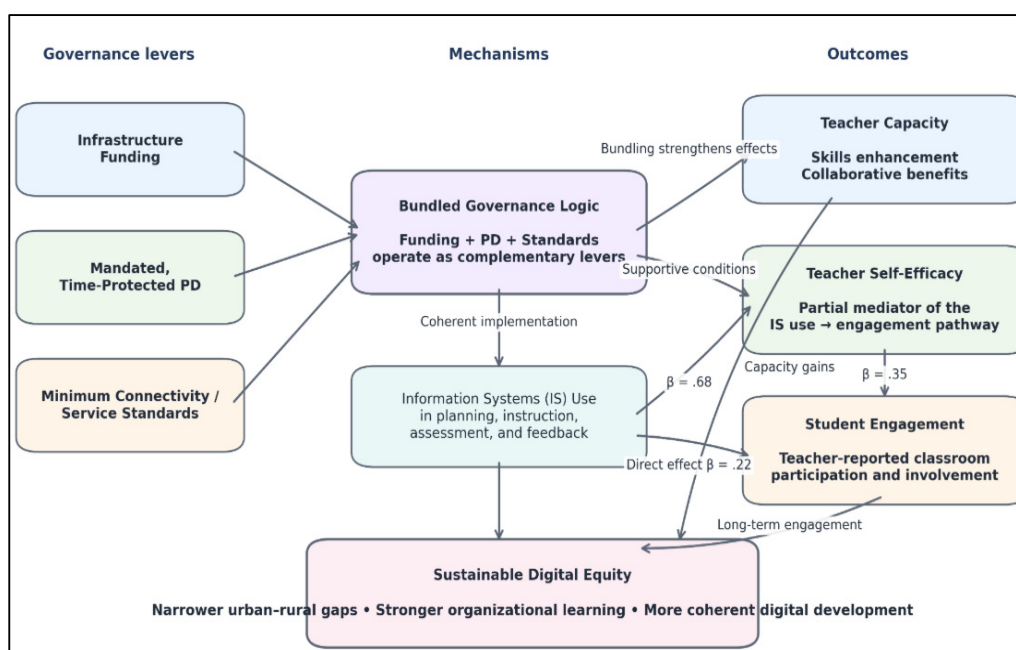
**RQ2.** Do the governance levers operate as complements? More specifically, do bundled configurations (Funding  $\times$  TPD, Funding  $\times$  Standards, TPD  $\times$  Standards) produce stronger effects on teacher capacity and engagement than single levers?

**RQ3.** Does teacher self-efficacy partially mediate the association between IS use and student engagement, and does this mediated pathway vary by career stage (age/experience) and locale?

**RQ4.** What equity effects emerge under different governance configurations, particularly with respect to narrowing rural–urban gaps in teacher capacity and student engagement?

By combining governance instruments with TPACK and Diffusion of Innovations, the study contributes to digital teacher education in three ways. First, it identifies which policy bundles make TPD more effective for in-service teachers. Second, it clarifies the mediating role of teacher self-efficacy in digitally enriched instruction. Third, it shows how equity-oriented governance can narrow second-order digital divides in primary schools and support more sustainable digital equity across diverse school contexts.

To clarify the conceptual and analytical structure of the study, Figure 1 presents the proposed relationships among the governance levers, information systems use, teacher self-efficacy, teacher capacity, student engagement, and sustainable digital equity. The figure summarizes the central argument that infrastructure funding, mandated and time-protected professional development, and minimum connectivity/service standards are expected to operate more effectively as a coordinated policy bundle than as isolated measures. It also illustrates the mediating role of teacher self-efficacy and the expected contribution of bundled governance to reducing urban–rural disparities in teacher capacity and engagement.



**Figure 1.** Conceptual and empirical model of sustainable digital equity, teacher self-efficacy, and student engagement in Greek primary schools.

As shown in Figure 1, the study is grounded in the assumption that sustainable digital equity is not produced by single policy instruments in isolation, but by the alignment of resources, standards, and professional learning conditions. In this framework, teacher self-efficacy is positioned as a key explanatory mechanism linking information systems use with student engagement, while bundled governance is expected to strengthen teacher capacity and narrow urban–rural gaps. The figure therefore provides an integrative overview of the model that guides the research questions, variable selection, and subsequent analyses.

## 2. Literature Review

Much of the educational technology literature has equated the success of information systems (IS) with individual-level adoption, treating teachers' motivation, beliefs, and self-efficacy as the primary drivers of use (Backfisch et al., 2021; Gebhardt et al., 2019; Georgiou et al., 2023). Although these dispositions are important, this line of work often attributes too much explanatory weight to attitudinal measures derived from self-report surveys while underestimating the organizational and

policy conditions that make sustained use possible. Two major limitations follow. First, an intention–behavior gap persists: positive attitudes rarely translate into routinized classroom practice when infrastructure, time, or targeted training are lacking (Al-Marouf et al., 2023; Mehta et al., 2019; Tondeur et al., 2018). Second, adoption studies rarely model the policy instruments—funding rules, minimum service standards, and mandated teacher professional development (TPD)—that shape whether digital tools produce measurable gains in teaching and learning. As a result, the field has not sufficiently shifted from asking who is willing to adopt technology to examining under which governance and professional learning conditions adoption leads to meaningful outcomes.

The COVID-19 pandemic intensified this problem by functioning as a stress test that accelerated IS uptake while also exposing structural constraints. Empirical studies documented heightened anxiety, uneven digital competence, and training bottlenecks (Guangul et al., 2020; Talidong & Toquero, 2020), but also teachers' agency, peer support, and improvised collaboration (Eradze et al., 2023). Post-pandemic research has reported gains in digital competence and highlighted the role of psychological adaptability and self-efficacy (Ivanov et al., 2025; Yang et al., 2024). Yet such gains appear to persist only where systems provide time-protected TPD, reliable infrastructure, and leadership routines that normalize digital practice (Dempsey & Mestry, 2023; Perry, 2023). In much of the literature, however, these enabling conditions remain treated as contextual background rather than as governance instruments whose separate and combined effects can be empirically examined.

A related limitation concerns the conceptual treatment of IS itself. Definitions often list platforms—learning management systems, student information systems, assessment tools, and collaboration environments—without distinguishing between administrative and instructional uses or clarifying the functional thresholds that make them educationally meaningful. This conceptual looseness introduces measurement ambiguity: increased SIS logins, for example, may reveal little about pedagogy, whereas assessment platforms may improve feedback only when connectivity and training exceed minimum operational thresholds. A socio-technical perspective therefore suggests that the value of IS depends jointly on technical service standards and capacity building through structured, aligned TPD. From a teacher education perspective, this raises an important question: do isolated investments in funding or standards systematically underperform compared with coordinated policy bundles that protect time for learning, model digital pedagogy, and support follow-up coaching?

Although teacher factors remain necessary, they are not sufficient. Motivation and acceptance explain some variation in IS use (Backfisch et al., 2021; Gebhardt et al., 2019; Mbatha, 2024; Wu, 2019), but this literature is often constrained by mono-method designs, context under-specification, and the omission of capacity requirements and equity conditions as explanatory factors. These limitations become particularly important when digital inequality is considered. Beyond first-order access gaps, second-order digital divides—differences in the effective use of technology—persist even in comparatively well-resourced systems (Lebeničnik & Istenič Starčič, 2020; van Dijk, 2017). Rural schools, in particular, tend to face weaker infrastructure, fewer local PD opportunities, and higher participation costs (Mustafa et al., 2024; Singh et al., 2021; Ventista et al., 2024a, 2024b). Even so, many studies stop short of testing how policy design shapes the distribution of teacher learning opportunities across contexts.

Professional development is similarly under-theorized when viewed from a governance perspective. TPACK provides a robust framework for understanding how pedagogy, content, and technology must be aligned for effective instruction (Mishra & Koehler, 2006), and research has shown that online, adaptive, and practice-oriented PD can strengthen digital skills and collaborative teaching practice (Budianto et al., 2023; Charania et al., 2023; Elmaadaway & Abouelenein, 2023). Nevertheless, PD is frequently treated as a one-off intervention rather than as a structured capacity regime with designable properties such as time protection, curricular alignment, accountability, and conditionality. During the pandemic, schools and teacher educators often assembled hybrid PD arrangements of uneven quality, while teachers relied heavily on informal peer learning when institutional support was limited (Dempsey & Mestry, 2023; Perry, 2023). The more consequential

question for teacher education, therefore, is not simply whether TPD is available, but how mandated, time-protected, and digitally aligned PD interacts with funding and service standards to produce durable gains in teacher capacity and student engagement.

Claims regarding student engagement also require caution. IS are often assumed to enhance personalization, monitoring, and active participation (Popescu et al., 2022; Viberg et al., 2020), yet much of the evidence relies on teacher-reported engagement, which is vulnerable to expectancy effects and contextual bias. Retaining engagement as a teacher-reported outcome is still defensible when its limitations are acknowledged and when it is interpreted alongside related indicators, such as PD outcomes or observed classroom practice. In this respect, modeling teacher self-efficacy as a mediator between IS use and engagement offers a more theoretically grounded alternative to simplistic claims that technology directly causes engagement. Such a model helps connect digital governance, TPD design, and classroom-level processes in a more coherent way.

Within the highly centralized but locally heterogeneous Greek primary education system, this perspective makes it possible to test whether allocation rules, minimum service standards, and mandated TPD operate as complements rather than substitutes, and whether bundled governance arrangements can narrow second-order digital divides, particularly for rural schools. The present study addresses this gap by examining how governance instruments, teacher self-efficacy, and IS use are jointly associated with teacher capacity, student engagement, and more sustainable forms of digital equity.

### 3. Methodology

#### 3.1. Research Design and Participants

This study employed a cross-sectional survey design to examine how governance conditions, information systems use, and professional development were associated with teacher capacity, self-efficacy, and student engagement in Greek primary schools. The target population consisted of in-service primary school teachers in Greece who had direct experience using information systems (IS) for professional and instructional purposes.

A stratified purposive sampling strategy was used to ensure representation across urban, suburban, and rural school contexts. This approach was considered appropriate because the study aimed to compare teachers working under different infrastructural and professional learning conditions rather than to produce a nationally representative random sample. Eligible participants were practicing primary school teachers employed in Greece and actively engaged in school-based instructional work involving digital platforms or information systems.

Data were collected online through a Google Forms questionnaire distributed to approximately 2,000 teachers via regional school networks and professional mailing lists. Participation was voluntary, and responses were collected anonymously. A total of 460 teachers completed the questionnaire, yielding a response rate of approximately 23%. Table 1 summarizes the demographic characteristics of the sample.

**Table 1.** Demographic characteristics of participants (N = 460).

Variable	Category	n	%
Gender	Female	280	60.9
	Male	180	39.1
Age (years)	20–30	90	19.6
	31–40	140	30.4
	41–50	130	28.3
	51+	100	21.7
Teaching experience	1–5 years	80	17.4
	6–10 years	120	26.1
	11–20 years	150	32.6

Highest degree	21+ years	110	23.9
	Bachelor's	200	43.5
	Master's	220	47.8
	Doctorate	40	8.7
School locale	Urban	180	39.1
	Suburban	150	32.6
	Rural	130	28.3

The study was guided by two complementary theoretical frameworks that are central to digital learning in teacher education. The first was **Technological Pedagogical Content Knowledge (TPACK)** (Mishra & Koehler, 2006), which conceptualizes effective technology integration as the intersection of content, pedagogy, and technology. The second was Diffusion of Innovations (DoI) (Rogers, as adapted in Mbatha, 2024), which explains how innovations spread within a social system as a function of perceived usefulness, ease of use, and contextual supports and constraints.

TPACK informed the construction of items related to IS use and professional development outcomes, particularly skills enhancement and collaborative benefits. By contrast, DoI informed the study's focus on perceived usefulness, social influence, and contextual barriers across career stages and school locales. Together, these frameworks provided the conceptual basis for examining how governance conditions, professional development, and information systems use relate to teacher learning and engagement.

Table 2 summarizes how each framework was operationalized in the study.

**Table 2.** Application of theoretical frameworks in the study.

Theoretical framework	Core concepts	Application in this study
TPACK	Integration of Content Knowledge (CK), Pedagogical Knowledge (PK), and Technological Knowledge (TK) for effective instructional design.	Informed the design of IS use and PD outcome items, focusing on how teachers align technology with pedagogy and subject content and how PD supports this alignment.
	Adoption and spread of innovations within a social system, influenced by perceived usefulness, ease of use, social influence, and contextual factors.	Guided the analysis of variation in IS adoption across age, experience, and locale, and the modelling of governance levers (funding, TPD, standards) as contextual enablers or constraints.

### 3.2. Instruments and Measures

Data were collected through an online questionnaire consisting of six main subscales and three policy-lever indices, all rated on 5-point Likert-type scales (1 = strongly disagree, 5 = strongly agree), unless otherwise indicated.

Where possible, questionnaire items were adapted from established international instruments addressing teachers' preparedness for digital technology use, technology-related self-efficacy, and online or blended professional development (e.g., Budianto et al., 2023; Georgiou et al., 2023; Philipson et al., 2019; Popescu et al., 2022; Viberg et al., 2020; Zeng et al., 2022). New items were developed for the policy-lever measures, drawing on recent OECD and UNESCO guidance on digital education as well as national research on primary school digitization in Greece (OECD, 2023; UNESCO, 2023; Ventista et al., 2024a, 2024b). All items were reviewed by two experts in educational technology and teacher professional development and were piloted with a small group of primary school teachers prior to full administration.

The instrument assessed the following constructs:

- **IS use:** frequency and intensity of information systems use across lesson planning, instruction, assessment, and feedback.
- **TPACK-aligned professional development outcomes:**
  - **Skills enhancement:** perceived improvement in the ability to design technology-rich lessons aligned with the curriculum.
  - **Collaborative benefits:** perceived improvement in collegial collaboration, including the sharing of materials and participation in professional learning communities focused on digital practice.
- **Digital teaching self-efficacy:** perceived capability to design and manage digitally enriched instruction and respond effectively to technical difficulties.
- **Motivation for digitally enriched instruction:** willingness to experiment with and invest time in new digital tools for teaching.
- **Perceived challenges:** technical barriers, administrative burden, training gaps, and lack of support.
- **Teacher-reported student outcomes:** student engagement and student digital competence when IS are used in teaching.
- **Policy-lever exposure:** perceived school-level exposure to:
  - infrastructure funding,
  - mandated, time-protected TPD, and
  - minimum connectivity and service standards.

Table 3 presents an overview of the constructs, number of items, and primary source base. The full English version of the questionnaire, including all items and their mapping to constructs and sources, is provided in Appendix A.

**Table 3.** *Questionnaire constructs, number of items, and main sources.*

<b>Construct / scale</b>	<b>No. of items</b>	<b>Main source(s)</b>
IS use	6	Viberg et al. (2020)
PD outcomes – Skills enhancement	4	Philipsen et al. (2019)
PD outcomes – Collaborative benefits	4	Philipsen et al. (2019)
Digital teaching self-efficacy	4	Viberg et al. (2020)
Motivation for digitally enriched instruction	3	Georgiou et al. (2023)
Perceived challenges	6	Timotheou et al. (2023)
Teacher-reported student engagement	3	Viberg et al. (2020)
Teacher-reported student digital competence	3	Viberg et al. (2020)
Policy lever – Infrastructure funding	3	OECD (2023)
Policy lever – Mandated, time-protected TPD	4	OECD (2023)
Policy lever – Minimum connectivity/service standards	4	OECD (2023)

Content validity was supported in two ways. First, items were adapted, where possible, from established international instruments addressing teachers' digital technology use, TPACK-oriented professional development, and technology-related self-efficacy and attitudes. Second, all items—including the policy-lever items developed for this study—were reviewed by two experts in educational technology and teacher professional development for clarity, relevance, and alignment with the intended constructs.

Construct validity was examined through exploratory factor analysis using principal-axis factoring with oblique rotation on the full set of questionnaire items. Sampling adequacy was good (KMO = 0.84), and Bartlett's test of sphericity was significant ( $p < .001$ ), indicating that the data were suitable for factor analysis. The extracted factors were consistent with the intended subscales, including IS use, professional development outcomes, self-efficacy and motivation, perceived

challenges, teacher-reported outcomes, and the three policy levers. Factor loadings were strong on their primary dimensions, with minimal cross-loadings across constructs.

Internal consistency reliability was high. Cronbach's alpha was .91 for the full instrument, and alpha coefficients for the individual subscales ranged from .85 to .89, indicating good to excellent reliability. Taken together, the clear factor structure and strong internal consistency support the psychometric adequacy of the questionnaire for use with in-service primary school teachers in digitally evolving educational contexts. For transparency and potential reuse, the full item set is provided in Appendix A.

#### 4. Data Analysis

Data were analyzed using IBM SPSS Statistics 24 and IBM SPSS AMOS 27. Descriptive statistics, including means, standard deviations, and percentages, were first computed for all study variables and subscales.

For RQ1, one-way analyses of variance (ANOVAs) were conducted to compare skills enhancement, collaborative benefits, and perceived challenges across school locales (urban, suburban, and rural). These analyses were followed by ordinary least squares (OLS) regression models with locale fixed effects and relevant controls, including gender, age, teaching experience, highest degree, and school size. Continuous predictors were standardized, and robust standard errors were applied.

For RQ2, interaction terms representing the hypothesized policy bundles (Funding  $\times$  TPD, Funding  $\times$  Standards, and TPD  $\times$  Standards) were added to the OLS models. Changes in explained variance ( $\Delta R^2$ ) were examined, and simple slopes were used to interpret significant interaction effects.

For RQ3, a mediation model was estimated using structural equation modeling (SEM) in AMOS 27, with IS use specified as a predictor of teacher-reported student engagement both directly and indirectly through digital teaching self-efficacy. Indirect effects were tested using bias-corrected bootstrapping based on 5,000 resamples. Model fit was evaluated using multiple indices and indicated good fit,  $\chi^2(51) = 87.32$ ,  $p = .002$ , CFI = .96, TLI = .95, RMSEA = .046, and SRMR = .034.

For RQ4, a Bundled Governance Index (BGI) was created by standardizing and averaging the three policy-lever indices. Interaction regression models including BGI  $\times$  locale were then estimated to derive predicted margins (means with 95% confidence intervals) for teacher skills. Effect sizes, including Cohen's  $d$ ,  $\eta^2$ , and standardized  $\beta$  coefficients, were reported where appropriate. Statistical significance was set at  $p < .05$ .

To strengthen the validity of the analyses, diagnostic and validation procedures were conducted before and after model estimation. Assumptions of normality, linearity, and multicollinearity were examined for the regression models, and robust standard errors were used to account for possible heteroscedasticity. For the SEM analysis, model adequacy was evaluated through multiple fit indices, while the indirect effect was validated through bias-corrected bootstrapping with 5,000 resamples. The Bundled Governance Index was constructed from standardized policy-lever scores to enhance comparability and reduce scale-related distortion across components.

#### 5. Ethical Considerations

Participation in the study was voluntary and anonymous. Before completing the online questionnaire, participants were informed about the purpose of the study, the academic use of the data, and their right to withdraw at any time prior to submission. Completion of the questionnaire was taken to indicate informed consent. No personally identifiable information was collected, and all responses were analyzed in aggregate form to protect confidentiality. The study was conducted in accordance with standard ethical principles for educational research involving adult participants and was approved by the relevant institutional ethics committee.

## 6. Results

All analyses controlled for gender, age, teaching experience, highest degree, and school size. Continuous predictors were standardized, and robust standard errors were used throughout.

### RQ1. Effects of Governance Levers on Teacher Capacity

Descriptive analyses indicated that urban teachers reported higher levels of skills enhancement and collaborative benefits than their suburban and rural counterparts, whereas rural teachers reported significantly greater technical barriers and training gaps. These patterns are consistent with uneven enabling conditions across school locales (see Table 4).

**Table 4.** One-Way ANOVA Results for Skills Enhancement, Collaboration, and Challenges by School Locale.

Variable	Urban M (SD)	Suburban M (SD)	Rural M (SD)	F(2, 457)	$\eta^2$
Skills enhancement	4.2 (0.8)	4.0 (0.9)	3.8 (1.1)	15.87***	.06
Collaborative benefits	4.5 (0.7)	4.4 (0.8)	3.9 (1.0)	22.35***	.09
Technical barriers	3.2 (1.0)	3.3 (1.1)	4.1 (1.3)	22.67***	.07
Administrative load	3.5 (1.1)	3.4 (1.2)	3.7 (1.3)	6.42**	.03
Training gaps	2.9 (1.0)	3.1 (1.2)	3.8 (1.4)	17.23***	.05

Note.  $p < .01$  \*\*,  $p < .001$  \*\*\*.

In the multivariate OLS models, mandated, time-protected TPD and minimum connectivity/service standards emerged as consistent positive predictors of both skills enhancement and collaborative benefits. By contrast, infrastructure funding alone was not a significant predictor once controls and the other governance levers were included. Model fit was substantial ( $R^2 \approx .36-.38$ ), indicating that the governance levers explained a meaningful proportion of variance in teacher capacity (see Table 5). Overall, teacher capacity was higher in settings where training was mandated and connectivity standards were enforced, whereas funding without these complementary conditions did not reliably translate into stronger practice.

**Table 5.** OLS effects of governance levers on teacher capacity.

Outcome	Funding $\beta$ [95% CI]	Mandated TPD $\beta$ [95% CI]	Standards $\beta$ [95% CI]	Locale FE	Controls	$R^2$
Skills enhancement	0.06 [-0.02, 0.14]	0.31 [0.22, 0.40]	0.24 [0.15, 0.33]	Yes	Yes	0.36
Collaborative benefits	0.04 [-0.04, 0.12]	0.34 [0.25, 0.42]	0.21 [0.12, 0.30]	Yes	Yes	0.38

Note. Predictors standardised/mean-centred; robust standard errors; controls: gender, age, teaching experience, highest degree, school size.

### RQ2. Complementarity (“Bundling”) of Governance Levers

To examine whether the governance levers operated as complements, interaction terms among funding, mandated TPD, and standards were added to the regression models. These interaction blocks produced small but meaningful gains in explained variance ( $\Delta R^2 \approx .03-.04$  for teacher capacity and  $\approx .02$  for student engagement; see Table 6).

The strongest interaction effects were observed for Funding  $\times$  TPD and TPD  $\times$  Standards. Funding predicted higher levels of teacher skills and student engagement only when paired with high exposure to mandated, time-protected TPD, whereas collaboration was strongest when TPD co-occurred with enforceable connectivity standards. As illustrated in Figure 2, the slope of funding was nearly flat at low levels of TPD exposure but clearly positive at high levels of TPD exposure. This pattern suggests that resources alone were insufficient unless accompanied by structured professional development.

**Table 6.** Interaction (“bundling”) models predicting capacity and engagement.

Outcome	Funding × TPD β [95% CI]	Funding × Standards β [95% CI]	TPD × Standards β [95% CI]	ΔR <sup>2</sup> (interactions)
Skills enhancement	0.13*** [0.06, 0.20]	0.05 [-0.02, 0.12]	0.08* [0.01, 0.15]	0.04***
Collaborative benefits	0.09* [0.02, 0.16]	0.04 [-0.03, 0.11]	0.12*** [0.05, 0.19]	0.03**
Student engagement	0.10** [0.03, 0.17]	0.05 [-0.02, 0.12]	0.11** [0.03, 0.19]	0.02**

Note. Standardised predictors; robust standard errors; same controls as Table 4.  $p < .05^*$ ,  $p < .01^{**}$ ,  $p < .001^{***}$ .

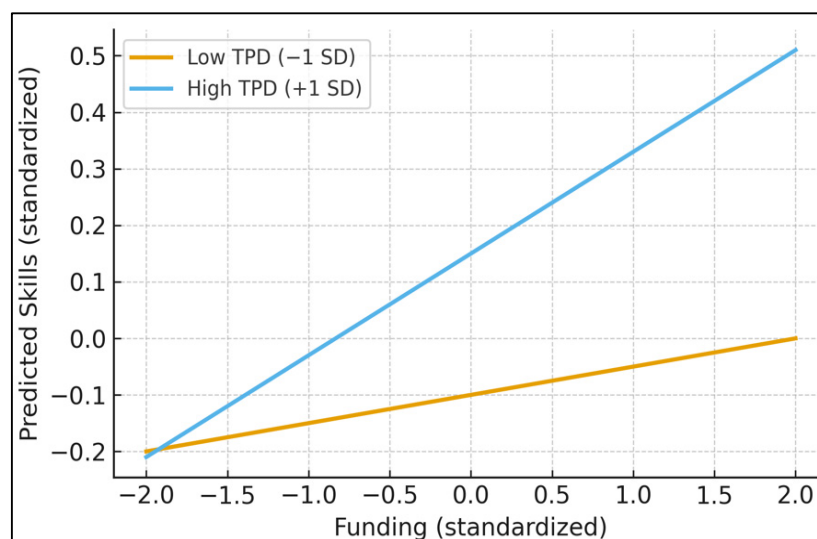
Figure 2 graphically depicts the interaction between infrastructure funding and mandated, time-protected TPD in predicting teacher skills enhancement, illustrating that funding has a meaningful positive effect only under conditions of high TPD exposure.

Predicted skills enhancement (Likert 1–5) as a function of infrastructure funding at low (–1 SD) and high (+1 SD) levels of mandated, time-protected TPD, holding covariates at their means. The slope of funding is near-zero at low TPD and clearly positive at high TPD, illustrating the complementarity between funding and training.

Overall, these results support a bundled governance logic: policy instruments reinforce rather than substitute for one another.

### RQ3. Mediation via teacher self-efficacy and heterogeneity

A path model was estimated to examine whether IS use predicts student engagement indirectly through teacher self-efficacy (see Table 7). IS use strongly predicted self-efficacy, self-efficacy predicted engagement, and the direct effect of IS use on engagement remained statistically significant, yielding a substantial indirect effect and indicating partial mediation. This pattern suggests that IS use is associated with engagement both directly and indirectly by strengthening teachers’ confidence in managing digitally enriched instruction.

**Figure 2.** Simple slopes of Funding × TPD predicting skills enhancement.

Multi-group analyses suggested that the mediated pathway was stronger among early-career teachers, whereas differences across school locales were negligible. This finding identifies self-efficacy as a key explanatory mechanism—particularly for teachers at earlier stages of their careers—

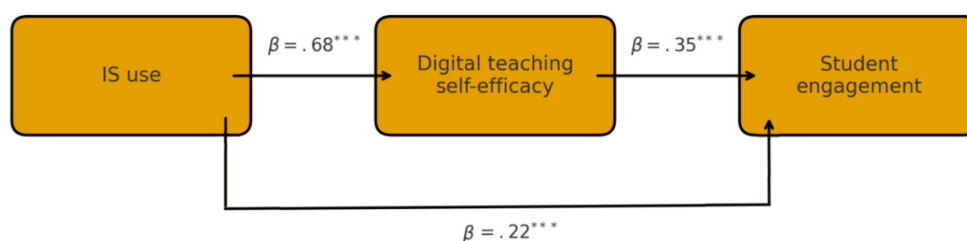
through which IS use and related professional development may translate into perceived student engagement.

**Table 7.** SEM coefficients for mediation model.

Path	$\beta$	95% CI	<i>p</i>
IS use → Self-efficacy	0.68	[0.62, 0.74]	< .001
Self-efficacy → Engagement	0.35	[0.26, 0.44]	< .001
IS use → Engagement (direct)	0.22	[0.12, 0.32]	< .001
Indirect (bootstrapped)	0.24	[0.17, 0.32]	—

Note. Standardised coefficients; N = 460; covariates: gender, age, teaching experience, highest degree, school size; indirect effect based on 5,000 bias-corrected bootstrap resamples.

Figure 3 presents the structural path model linking IS use to teacher-reported student engagement, highlighting both the direct path and the indirect pathway operating through digital teaching self-efficacy.



**Figure 3.** Mediation model: IS use → Teacher self-efficacy → Student engagement.

#### RQ4. Equity effects (rural–urban gaps) under governance configurations

To quantify equity-related effects, a Bundled Governance Index (BGI) was created by combining standardized scores for infrastructure funding, mandated TPD, and connectivity/service standards. Interaction models including BGI × locale were then used to estimate predicted margins for teacher skills.

Under low bundling (BGI = -1 SD), the urban–rural gap in teacher skills was 0.37 Likert points in favor of urban schools. Under high bundling (BGI = +1 SD), this gap narrowed to 0.12, representing approximately a two-thirds reduction (see Table 8 and Figure 4). Suburban schools also moved closer to urban levels as bundling increased.

Taken together, these findings suggest that coherent, bundled governance—linking funding, mandated TPD, and enforceable connectivity standards—not only strengthens teacher capacity and engagement overall but also narrows rural–urban disparities, thereby supporting a more equitable digital learning environment for teachers and students.

**Table 8.** Equity Effects: Predicted Margins for Teacher Skills by Bundled Governance Index and Locale.

BGI level	Urban M [95% CI]	Suburban M [95% CI]	Rural M [95% CI]	Urban–Rural gap [95% CI]
Low (-1 SD)	4.15 [4.05, 4.24]	4.00 [3.89, 4.12]	3.78 [3.66, 3.90]	0.37 [0.23, 0.51]
High (+1 SD)	4.38 [4.30, 4.46]	4.28 [4.18, 4.38]	4.26 [4.16, 4.36]	0.12 [0.01, 0.23]

Figure 4 shows the predicted mean levels of teacher skills across urban, suburban, and rural schools under low versus high levels of the BGI, making visible how stronger bundling is associated with a narrowing of the urban–rural gap.

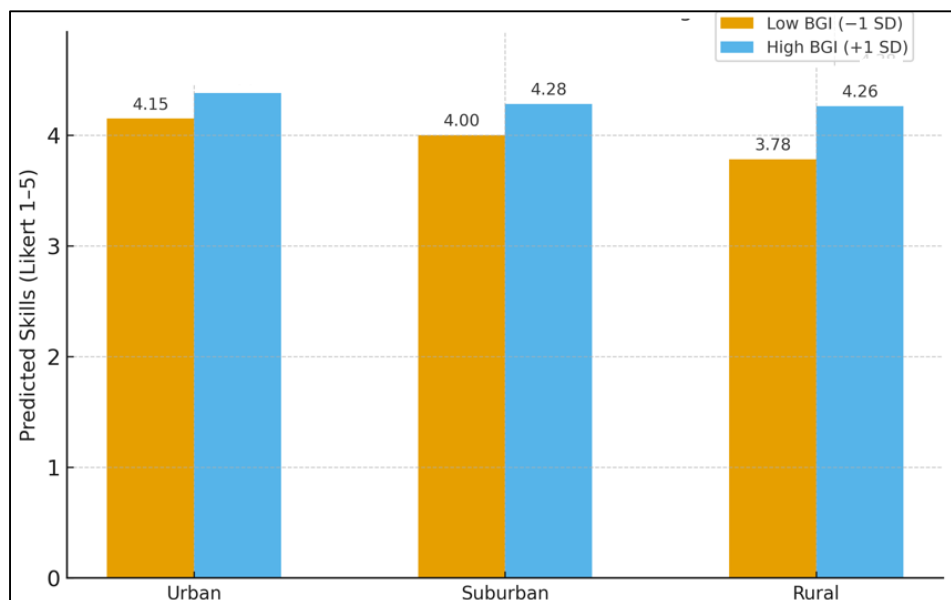


Figure 4. Predicted margins: Bundled Governance  $\times$  Locale  $\rightarrow$  Skills.

## 7. Discussion

This study examined how different configurations of information systems (IS) governance—namely infrastructure funding, mandated and time-protected teacher professional development (TPD), and minimum connectivity/service standards—relate to in-service primary teachers' digital capacity and perceived student engagement. Across the analyses, a consistent pattern emerged: resources translated into classroom change only when they were embedded in coherent capacity-building arrangements, and teacher self-efficacy functioned as a proximal mechanism linking IS use to engagement (Mishra & Koehler, 2006; Scherer et al., 2019; Zee & Koomen, 2016; Zeng et al., 2022). These findings support international calls to move beyond hardware-first approaches toward coordinated digital education strategies (Boeskens & Meyer, 2025; OECD, 2023; UNESCO, 2023). In this sense, digital equity is framed not as a one-time outcome of post-COVID investment, but as a sustainability challenge requiring aligned governance, professional learning, and service guarantees.

The findings for **RQ1** showed that mandated, time-protected TPD and enforceable connectivity standards were robust predictors of teachers' reported skills enhancement and collaborative benefits, whereas funding alone lost significance once controls were introduced. From a teacher education perspective, this reinforces a central TPACK argument: sustainable technology integration depends on opportunities to align tools with pedagogy and content through structured, practice-proximal learning (Mishra & Koehler, 2006; Philippsen et al., 2019). The findings also echo pandemic-era research documenting an intention-behavior gap, in which positive attitudes toward digital tools do not automatically lead to routine classroom use in the absence of time, support, and reliable infrastructure (Al-Marouf et al., 2023; Georgiou et al., 2023; Mehta et al., 2019; Tondeur et al., 2018). For providers of in-service and blended programs, the results suggest that the institutional conditions under which PD is protected and resourced may matter as much as its instructional content.

The findings for **RQ2** further indicated that the governance levers operated as complements rather than substitutes. Funding was associated with stronger gains in teacher skills and student engagement only when combined with high exposure to mandated TPD, whereas collaboration was highest when TPD co-occurred with minimum connectivity and service standards. These more-than-additive effects are consistent with policy-mix theory, which argues that coherent bundles of instruments are more effective than isolated measures (Howlett & del Río, 2015; Kern et al., 2019). They also align with school-level evidence showing that digital tools produce more meaningful instructional change when teachers have protected time, reliable platforms, and ongoing support

(Perry, 2023; Timotheou et al., 2023). From a teacher education perspective, these results suggest that the impact of digital learning programs depends not only on pedagogical design, but also on the governance environment in which such programs are implemented—specifically, whether PD is mandatory, scheduled, practice-linked, and backed by minimum infrastructure guarantees.

With respect to RQ3, the mediation analysis showed that IS use was associated with teacher-reported student engagement both directly and indirectly through teacher self-efficacy, with the indirect pathway appearing stronger among early-career teachers. This finding is consistent with prior syntheses linking teacher self-efficacy to classroom processes and technology adoption (Scherer et al., 2019; Zee & Koomen, 2016), as well as with evidence that TPACK and digital competence are strengthened when PD is sequenced, coached, and embedded in practice (Farjon et al., 2019; Huang et al., 2024; Philippsen et al., 2019). The implication is that digital learning initiatives for teachers should explicitly target self-efficacy through scaffolded experimentation, peer collaboration, and feedback, rather than focusing exclusively on technical skills or platform navigation. The stronger mediated pathway among early-career teachers further suggests that confidence-building may be especially important during the early stages of professional development.

The findings for RQ4 showed that higher levels of bundled governance were associated with substantially smaller urban–rural gaps in teacher skills. This result resonates with scholarship on first- and second-order digital divides and with broader arguments for context-sensitive support in underserved schools (Lebeničnik & Istenič Starčič, 2020; Mustafa et al., 2024; Singh et al., 2021; van Dijk, 2017; Walker et al., 2022). It also aligns with recent work on digital capacity in Greek primary schools (Ventista et al., 2024a, 2024b). For policymakers and teacher educators, the implication is clear: equity-oriented digital strategies should combine targeted PD for rural teachers with guaranteed connectivity, adequate devices, and accessible technical support, rather than assuming that generic online provision can compensate for structural constraints.

Several limitations should also be considered. First, the study relied on cross-sectional, teacher-reported data for both governance exposure and outcomes, raising the possibility of common-method bias and limiting causal inference. Perceived mandates and standards may also be associated with broader organizational conditions—such as leadership routines, scheduled collaboration, or local IT support—that were not directly measured (Burke et al., 2018; Escibano et al., 2020; Timotheou et al., 2023; Zheng et al., 2024). Second, strong mandates and audit regimes may encourage checklist-style compliance or increase workload if they are not accompanied by release time, coaching, and improvement-oriented accountability (Garcia & Lee, 2020; Perry, 2023). Third, the expansion of IS introduces data governance and privacy concerns (OECD, 2023; UNESCO, 2023), which may shape teachers' willingness to experiment with digital tools in authentic instructional ways.

Future research could build on these findings in several ways. Longitudinal and quasi-experimental designs would help clarify how changes in governance bundles over time affect teacher capacity, self-efficacy, and student outcomes. Multi-source designs that combine survey responses with classroom observations, administrative data, and learning analytics would strengthen the evidence base and reduce reliance on single-informant measures. Further studies could also compare alternative PD architectures—such as micro-credential pathways, coaching-based models, and one-off workshops—under different policy conditions. Such work would help clarify how teacher education design and governance arrangements can be aligned so that investments in digital tools, professional development, and infrastructure produce more sustainable and equitable improvements in teaching and learning.

## 8. Conclusions

This study examined how different configurations of information systems (IS) governance shape primary teachers' digital capacity and perceived student engagement. The findings indicate that infrastructure funding alone is insufficient; improvements in skills, collaboration, and engagement were most evident when funding was coupled with mandated, time-protected teacher professional development (TPD) and minimum connectivity/service standards. Within this policy bundle, teacher

self-efficacy emerged as a proximal mechanism linking IS use to engagement, underscoring the importance of professional development that explicitly strengthens teachers' confidence and competence in digitally enriched pedagogy. The equity analyses further showed that bundled governance can narrow urban–rural gaps in teacher capacity, highlighting the potential of coordinated digital strategies to support teachers in underserved contexts.

For teacher education and professional learning, these findings suggest that the effectiveness of digital initiatives depends not only on the quality of PD content, but also on the conditions under which teachers participate, including protected time, reliable infrastructure, and clear expectations for classroom use. Designing PD as part of a broader governance bundle, rather than as an isolated add-on, appears especially important for early-career teachers and for schools operating under structural constraints.

At the same time, the conclusions should be interpreted with caution. The cross-sectional, teacher-reported design limits causal inference and may be influenced by unobserved organizational factors, while the Greek primary school context constrains broader generalizability. Future research should therefore combine longitudinal or quasi-experimental designs with multi-source data, including surveys, observations, and learning analytics, to examine how changes in governance arrangements over time shape teachers' digital practices and student outcomes. Even with these limitations, the practical implication is clear: meaningful digital learning requires attention not only to the provision of tools, but also to the governance conditions that enable teachers to use them effectively within a sustainable and equitable digital education system.

## Appendix A

### Questionnaire items and response scale

Item	1	2	3	4	5
1	I use digital learning platforms (e.g., LMS) when planning my lessons.				
2	I use information systems to deliver instructional activities during lessons.				
3	I use digital tools to assess students' work (e.g., quizzes, assignments).				
4	I use information systems to provide feedback to students on their learning.				
5	I use digital platforms to communicate with students and/or families about learning.				
6	I regularly review student data from information systems to adjust my teaching.				
7	Recent professional development has improved my ability to design technology-rich lessons aligned with the curriculum.				
8	I feel more capable of choosing digital tools that support my pedagogical goals.				
9	Professional development has helped me integrate digital resources into my subject teaching.				
10	I can better adapt my teaching strategies when using digital platforms after recent professional development.				
11	Professional development has strengthened my collaboration with colleagues around digital teaching.				

12	I now share and co-develop digital teaching materials with other teachers.
13	I participate more often in professional learning communities focused on digital practice.
14	Professional development has helped us develop common approaches to using digital tools in our school.
15	I feel confident designing lessons that make effective use of digital platforms.
16	I can solve most problems that arise when I use information systems in my teaching.
17	I feel capable of helping students when they face difficulties with digital tools.
18	I can adapt my teaching when technology does not work as expected.
19	I am motivated to experiment with new digital tools in my classroom.
20	Using digital technologies in my teaching fits well with how I like to teach.
21	I am willing to invest time in learning how to use new information systems for teaching.
22	Unreliable internet connection or equipment limits my use of information systems in teaching.
23	Administrative requirements in digital platforms (e.g., data entry, reporting) take too much of my time.
24	I do not receive enough training on how to use digital tools pedagogically.
25	Lack of on-site technical support makes it difficult to integrate technology in my lessons.
26	Limited access to up-to-date devices (e.g., computers, tablets) constrains my use of digital tools.
27	Time pressure in the school timetable leaves little room to prepare digitally enriched lessons.
28	When I use digital platforms, my students participate more actively in lessons.
29	Information systems help my students collaborate with each other on learning tasks.
30	Digital activities help students take more responsibility for their own learning.
31	My students' digital skills (e.g., navigating platforms, using tools) have improved over time.
32	Most students can work independently with the digital tools we use in class.
33	Students are able to use digital platforms to access and manage their learning materials.
34	Our school has received targeted funding for digital infrastructure (devices, platforms, connectivity) in recent years.
35	Recent funding has significantly improved our school's digital equipment.

36	Lack of funding limits our ability to maintain or upgrade digital infrastructure.
37	I am required to attend accredited professional development on digital pedagogy and assessment.
38	Time for digital professional development is protected in our school timetable.
39	Participation in digital professional development is monitored by school or regional authorities.
40	Professional development on digital teaching is clearly linked to expectations for classroom practice.
41	Our school must meet explicit minimum standards for internet connectivity (e.g., bandwidth).
42	Our school must meet explicit minimum standards for platform availability or uptime.
43	Compliance with digital service standards is monitored by regional or national authorities.
44	When our school does not meet digital service standards, we receive support to address the problem.

**Note.** Response scale: 1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree, 5 = strongly agree. Item groupings: • Items 1–6 = IS use • Items 7–10 = PD outcomes – Skills enhancement • Items 11–14 = PD outcomes – Collaborative benefits • Items 15–18 = Digital teaching self-efficacy • Items 19–21 = Motivation for digitally enriched instruction • Items 22–27 = Perceived challenges • Items 28–30 = Teacher-reported student engagement • Items 31–33 = Teacher-reported student digital competence • Items 34–36 = Policy lever – Infrastructure funding • Items 37–40 = Policy lever – Mandated, time-protected TPD • Items 41–44 = Policy lever – Minimum connectivity/service standards.

## References

- Al-Marroof, R. S., Salloum, S. A., Hassanien, A. E., & Shaalan, K. (2023). Fear from COVID-19 and technology adoption: The impact of Google Meet during Coronavirus pandemic. *Interactive Learning Environments*, 31(3), 1293–1308. <https://doi.org/10.1080/10494820.2020.1830121>
- Azubuikwe, O. B., Adegboye, O., & Quadri, H. (2021). Who gets to learn in a pandemic? Exploring the digital divide in remote learning during the COVID-19 pandemic in Nigeria. *International Journal of Educational Research Open*, 2, 100022. <https://doi.org/10.1016/j.ijedro.2020.100022>
- Backfisch, I., Lachner, A., Stürmer, K., & Scheiter, K. (2021). Variability of teachers' technology integration in the classroom: A matter of utility! *Computers & Education*, 166, Article 104159. <https://doi.org/10.1016/j.compedu.2021.104159>
- Boeskens, L., & Meyer, K. (2025). *Policies for the digital transformation of school education: Evidence from the Policy Survey on School Education in the Digital Age* (OECD Education Working Papers, No. 328). OECD Publishing. <https://doi.org/10.1787/464dab4d-en>
- Budianto, L., Arifani, Y., Wardhono, A., & Poedjiastutie, D. (2023). The TPACK level of in-service EFL teacher online professional training: The perspectives of teachers, students, and trainers. *Journal of Digital Learning in Teacher Education*, 39(2), 87–101. <https://doi.org/10.1080/21532974.2023.2167024>
- Burke, P. F., Schuck, S., Aubusson, P., Kearney, M., & Frischknecht, B. (2018). Exploring teacher pedagogy, stages of concern and accessibility as determinants of technology adoption. *Technology, Pedagogy and Education*, 27(2), 149–163. <https://doi.org/10.1080/1475939X.2017.1387602>
- Charania, A., Paltiwale, S., Sen, S., Sarkar, D., & Bakshani, U. (2023). Leading edge use of technology for teacher professional development in Indian schools. *Education Sciences*, 13(4), Article 386. <https://doi.org/10.3390/educsci13040386>

- Dempsey, T., & Mestry, R. (2023). Teachers' perceptions and experiences of navigating continuing professional development during the COVID-19 pandemic. *Education Sciences*, 13(9), 1–16. <https://doi.org/10.3390/educsci13090933>
- Elmaadaway, M. A. N., & Abouelenein, Y. A. M. (2023). In-service teachers' TPACK development through an adaptive e-learning environment (ALE). *Education and Information Technologies*, 28(6), 8273–8298. <https://doi.org/10.1007/s10639-022-11477-8>
- Eradze, M., De Martino, D., Tinterri, A., Albó, L., Bardone, E., Sunar, A. S., & Dipace, A. (2023). After the pandemic: Teacher professional development for digital educational innovation. *Education Sciences*, 13(5), Article 432. <https://doi.org/10.3390/educsci13050432>
- Escribano, R., Treviño, E., Nussbaum, M., Torres Irribarra, D., & Carrasco, D. (2020). How much does the quality of teaching vary at under-performing schools? Evidence from classroom observations in Chile. *International Journal of Educational Development*, 72, Article 102125. <https://doi.org/10.1016/j.ijedudev.2019.102125>
- Farjon, D., Smits, A., & Voogt, J. (2019). Technology integration of preservice teachers explained by attitudes and beliefs, competency, access, and experience. *Computers & Education*, 130, 81–93. <https://doi.org/10.1016/j.compedu.2018.11.010>
- Garcia, A., & Lee, C. H. (2020). Equity-centered approaches to educational technology. In M. J. Bishop, E. Boling, J. Elen, & V. Svihla (Eds.), *Handbook of research in educational communications and technology* (pp. 129–144). Springer. [https://doi.org/10.1007/978-3-030-36119-8\\_10](https://doi.org/10.1007/978-3-030-36119-8_10)
- Gebhardt, E., Thomson, S., Ainley, J., & Hillman, K. (2019). Teacher gender and ICT. In *Gender differences in computer and information literacy* (IEA Research for Education, Vol. 8, pp. 53–68). Springer. [https://doi.org/10.1007/978-3-030-26203-7\\_5](https://doi.org/10.1007/978-3-030-26203-7_5)
- Georgiou, D., Trikoili, A., & Kester, L. (2023). Rethinking determinants of primary school teachers' technology acceptance during the COVID-19 pandemic. *Computers & Education Open*, 4, Article 100145. <https://doi.org/10.1016/j.caeo.2023.100145>
- Ghanbaripour, A. N., Talebian, N., Miller, D., Tumpa, R. J., Zhang, W., Golmoradi, M., & Skitmore, M. (2024). A systematic review of the impact of emerging technologies on student learning, engagement, and employability in built environment education. *Buildings*, 14(9), 2769. <https://doi.org/10.3390/buildings14092769>
- Guangul, F. M., Suhail, A. H., Khalit, M. I., & Khidhir, B. A. (2020). Challenges of remote assessment in higher education in the context of COVID-19: A case study of Middle East College. *Educational Assessment, Evaluation and Accountability*, 32(4), 519–535. <https://doi.org/10.1007/s11092-020-09340-w>
- Howlett, M., & del Río, P. (2015). The parameters of policy portfolios: Verticality and horizontality in design spaces and their consequences for policy mix formulation. *Environment and Planning C: Government and Policy*, 33(5), 1233–1245. <https://doi.org/10.1177/0263774X15610059>
- Huang, L., Liang, M., Xiong, Y., Wu, X., & Lim, C. P. (2024). A systematic review of technology-enabled teacher professional development during COVID-19 pandemic. *Computers & Education*, 223, 105168. <https://doi.org/10.1016/j.compedu.2024.105168>
- Ivanov, A., Radonjić, A., Stošić, L., Krčadinac, O., Đokić, D. B., & Đokić, V. (2025). Teachers' digital competencies before, during, and after the COVID-19 pandemic. *Sustainability*, 17(5), Article 2309. <https://doi.org/10.3390/su17052309>
- Kern, F., Rogge, K. S., & Howlett, M. (2019). Policy mixes for sustainability transitions: New approaches and insights through bridging innovation and policy studies. *Research Policy*, 48(10), Article 103832. <https://doi.org/10.1016/j.respol.2019.103832>
- Lebeničnik, M., & Istenič Starčič, A. (2020). Examining the contemporary digital divide of university students with specific reference to students with special educational needs. *British Journal of Educational Technology*, 51(6), 2422–2441. <https://doi.org/10.1111/bjet.12920>
- Mbatha, B. (2024). Diffusion of innovations: How adoption of new technology spreads in society. In D. Ocholla, O. B. Onyancha, & A. O. Adesina (Eds.), *Information, knowledge, and technology for teaching and research in Africa* (pp. 1–18). Springer. [https://doi.org/10.1007/978-3-031-60267-2\\_1](https://doi.org/10.1007/978-3-031-60267-2_1)
- Mehta, A., Morris, N. P., Swinnerton, B., & Homer, M. (2019). The influence of values on e-learning adoption. *Computers & Education*, 141, Article 103617. <https://doi.org/10.1016/j.compedu.2019.103617>

- Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record*, 108(6), 1017–1054. <https://doi.org/10.1111/j.1467-9620.2006.00684.x>
- Mustafa, F., Nguyen, H. T. M., & Gao, X. (2024). The challenges and solutions of technology integration in rural schools: A systematic literature review. *International Journal of Educational Research*, 126, Article 102380. <https://doi.org/10.1016/j.ijer.2024.102380>
- OECD. (2023). *OECD digital education outlook 2023: Towards an effective digital education ecosystem*. OECD Publishing. <https://doi.org/10.1787/c74f03de-en>
- Perry, E. (2023). Teacher professional development in changing circumstances: The impact of COVID-19 on schools' approaches to professional development. *Education Sciences*, 13(1), Article 48. <https://doi.org/10.3390/educsci13010048>
- Philipsen, B., Tondeur, J., Pareja Roblin, N., Vanslambrouck, S., & Zhu, C. (2019). Improving teacher professional development for online and blended learning: A systematic meta-aggregative review. *Educational Technology Research and Development*, 67(5), 1145–1174. <https://doi.org/10.1007/s11423-019-09645-8>
- Polydoros, G. (2025). Harnessing AI and digital tools for micro-credentialing in mathematics education, enhancing learning outcomes for students with learning difficulties. In G. Durak & S. Çankaya (Eds.), *Integrating micro-credentials with AI in open education* (pp. 195–216). IGI Global. <https://www.igi-global.com/chapter/harnessing-ai-and-digital-tools-for-micro-credentialing-in-mathematics-education/361813>
- Popescu, D.-M., Aviana (Bojan), A.-E., & Halip, L. (2022). The importance of information technology in the activity and professional development of teachers. *LUMEN Proceedings*, 18, 168–175. <https://doi.org/10.18662/lumproc/gidtp2022/17>
- Saad, D., Verner, I., & Rosenberg Kim, R. B. (2024). Influential factors in teachers' adoption of robotics activities within STEM education. In R. Balogh, D. Obdržálek, & M. Fislake (Eds.), *Robotics in education: Proceedings of the RiE 2024 Conference* (Lecture Notes in Networks and Systems, Vol. 1084, pp. 77–88). Springer. [https://doi.org/10.1007/978-3-031-67059-6\\_8](https://doi.org/10.1007/978-3-031-67059-6_8)
- Scherer, R., Siddiq, F., & Tondeur, J. (2019). The technology acceptance model (TAM): A meta-analytic structural equation modeling approach to explaining teachers' adoption of digital technology in education. *Computers & Education*, 128, 13–35. <https://doi.org/10.1016/j.compedu.2018.09.009>
- Singh, A., Gupta, K., & Yadav, V. K. (2021). Adopting e-learning facilities during COVID-19: Exploring perspectives of teachers working in Indian public-funded elementary schools. *Education 3–13*, 51(1), 26–40. <https://doi.org/10.1080/03004279.2021.1948091>
- Talidong, K. J. B., & Toquero, C. M. D. (2020). Philippine teachers' practices to deal with anxiety amid COVID-19. *Journal of Loss and Trauma*, 25(6–7), 573–579. <https://doi.org/10.1080/15325024.2020.1759225>
- Timotheou, S., Miliou, O., Dimitriadis, Y., Villagrà Sobrino, S., Giannoutsou, N., Cachia, R., Martínez Monés, A., & Ioannou, A. (2023). Impacts of digital technologies on education and factors influencing schools' digital capacity and transformation: A literature review. *Education and Information Technologies*, 28, 6695–6726. <https://doi.org/10.1007/s10639-022-11431-8>
- Tondeur, J., Aesaert, K., Prestridge, S., & Consuegra, E. (2018). A multilevel analysis of what matters in the training of pre-service teachers' ICT competencies. *Computers & Education*, 122, 32–42. <https://doi.org/10.1016/j.compedu.2018.03.002>
- UNESCO. (2023). *Global education monitoring report 2023/4: Technology in education—A tool on whose terms?* UNESCO Publishing. <https://doi.org/10.54676/UZQV8501>
- van Dijk, J. (2017). Digital divide: Impact of access. In P. Rössler, C. A. Hoffner, & L. van Zoonen (Eds.), *The international encyclopedia of media effects* (pp. 1–11). John Wiley & Sons. <https://doi.org/10.1002/9781118783764.wbieme0045>
- Ventista, O. M., Kolokitha, M., Tsani, P., Polydoros, G., & Arkoumanis, G. (2024a). Achieving digital education in primary schools: Success factors and policy recommendations. *Policy Futures in Education*, 22(8), 1794–1814. <https://doi.org/10.1177/14782103241238825>
- Ventista, O. M., Tsani, P., Brown, C., Coe, R., & Polydoros, G. (2024b). Technology use and integration in state-funded primary schools: A structural equation model. *Education 3–13*, 1–17. <https://doi.org/10.1080/03004279.2024.2351013>

- Viberg, O., Mavroudi, A., Khalil, M., & Bälter, O. (2020). Validating an instrument to measure teachers' preparedness to use digital technology in their teaching. *Nordic Journal of Digital Literacy*, 15(1), 38–54. <https://doi.org/10.18261/issn.1891-943x-2020-01-04>
- Walker, H., Hennessy, S., & Pimmer, C. (2022). Trialling open educational resources for technology-supported teacher professional development in rural Zimbabwe. *Research Papers in Education*, 38(4), 568–592. <https://doi.org/10.1080/02671522.2022.2034925>
- Wang, J., & Fan, W. (2025). The effect of ChatGPT on students' learning performance, learning perception, and higher-order thinking: Insights from a meta-analysis. *Humanities and Social Sciences Communications*, 12, Article 621. <https://doi.org/10.1057/s41599-025-04787-y>
- Wu, C. H. (2019). Adoption of innovative ICT-enabled systems for analysis- and intuition-styled teachers in primary schools. In A. Tatnall (Ed.), *Encyclopedia of education and information technologies*. Springer. [https://doi.org/10.1007/978-3-319-60013-0\\_174-1](https://doi.org/10.1007/978-3-319-60013-0_174-1)
- Yang, Y.-F., Tseng, C. C., & Lai, S.-C. (2024). Enhancing teachers' self efficacy beliefs in AI based technology integration into English speaking teaching through a professional development program. *Teaching and Teacher Education*, 144, Article 104582. <https://doi.org/10.1016/j.tate.2024.104582>
- Zee, M., & Koomen, H. M. Y. (2016). Teacher self-efficacy and its effects on classroom processes, student academic adjustment, and teacher well-being: A synthesis of 40 years of research. *Review of Educational Research*, 86(4), 981–1015. <https://doi.org/10.3102/0034654315626801>
- Zeng, Y., Wang, Y., & Li, S. (2022). The relationship between teachers' information technology integration self-efficacy and TPACK: A meta-analysis. *Frontiers in Psychology*, 13, Article 1091017. <https://doi.org/10.3389/fpsyg.2022.1091017>
- Zheng, L., Liu, T., Feng, Y., Gu, X., & Yu, M.-H. (2024). Dynamic teacher's technology adoption during the COVID-19 pandemic. *SAGE Open*, 14(2). <https://doi.org/10.1177/21582440241237858>

**Disclaimer/Publisher's Note:** The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.