

Supplementary Material S2. Key Success Factors in Basic Education Digital Transformation — Multi-Stage Thematic Coding Protocol

I. Research Questions

1. KSF Identification: What are the key success factors (KSFs) for digital transformation in basic education? How can they be operationalized and measured?
2. Relationship Paths: What kinds of inter-factor dynamics (direct, mediating, moderating, chain, configurational) are evidenced in the empirical literature?
3. Integrative Framework: How can dispersed factors be integrated into an interpretable and generalizable analytical backbone?

II. Coding Strategy Overview (S2.1)

This study adopts a multi-stage thematic coding strategy to systematically extract and construct KSFs and factor relationship paths for digital transformation in basic education. The coding process follows a mixed inductive–deductive approach: data-driven thematic analysis is primary, with organizational change theory, digital transformation literature, and education digital maturity models serving as theoretical references to ensure rigor, traceability, and theoretical abstraction.

Stage 1: Open Coding → Identify basic concepts (driver / enabler / barrier / governance / implementation) ;

Stage 2: Axial Coding→Merge into secondary factor categories + measurable indicators ;

Stage 3: Selective Coding→Integrate into PPTE four-dimensional framework + path model.

Table S1. Quality Strategy and Approach

Quality Strategy	Approach
Full-text Review	Full-text coding of abstracts, methods, results, and discussions from 36 empirical studies
Traceability	Each open code annotated with document ID, type of meaning unit, and page/paragraph reference
Theoretical Saturation	Rate of new code generation <5% after the 30th study; no new codes after the 35th study
Mixed Logic	Inductive extraction combined with deductive categorization based on organizational change theories (e.g., PPT, TOE, TAM)

III. Open Coding (S2.2)

3.1 Objectives and Units

Objective: Extract explicit factors and implicit mechanisms related to digital transformation in basic education from the included empirical studies.

Table S2. Meaning-unit types

Type	Description	Examples
Driving Factors	Forces initiating the transformation	Policy drivers, demands for quality, impact of the pandemic

Enabling Factors	Conditions facilitating the transformation	Favorable conditions, organizational commitment, content quality
Barriers	Factors hindering the transformation	Digital divide, path dependency, resource scarcity
Governance Mechanisms	Organizational management and coordination rules	Process control, monitoring and evaluation, organizational coordination
Implementation Conditions	Operational conditions required for execution	Training mechanisms, platform interoperability, breakdown of tasks into stages



02_Open_Coding

Output: _Table.csv

3.2 Operational Rules

Analysis unit: Conclusion sentences, model variables, path-coefficient statements, configurational condition descriptions .

Naming: Noun phrases or action phrases, e.g., teachers' digital competence, students' digital literacy, school leadership and vision, professional development mechanisms, phase division and task decomposition, curriculum“Ctechnology integration.

Record fields: Open-code ID, open-code name, factor type, literature ID, excerpt, PPTE dimension, secondary factor category, merged KSF.

3.3 Open-Code Example Library (Extracted in This Study, Selected)

Table S3. Open-Code Example Library

Open Code	Factor Type	Secondary Category	Merged KSF	Source Literature
OC001 Teacher digital competence and TPACK	Enabling factor	Teacher literacy	Teacher digital literacy	L06/L18/L19
OC004 Teacher training and professional development	Implementation condition	Teacher literacy	Teacher professional development support	L08/L20
OC019 Performance expectancy and technology acceptance	Enabling factor	Teacher attitude	Willingness and attitude towards tech adoption	L08/L21
OC003 Principal digital leadership	Driver factor	Leadership	Administrator digital leadership	L09/L14/L16
OC038 IT organization and dedicated posts	Implementation condition	Leadership	CIO system and information organization construction	L01/L15/L36
OC020 Digital strategic planning	Driver factor	Strategic planning	Digital strategy and planning formulation	L01/L07/L36
OC016 Monitoring, evaluation, and quality improvement	Governance mechanism	Quality assurance	Quality assurance and continuous improvement	L02/L15/L36
OC006 Curriculum and	Implementation	Teaching	Curriculum integration and	L03/L24

technology integration	condition	application	teaching application	
OC012 Digital value identification	Enabling factor	Culture construction	Digital culture construction	L01/L04
OC007 Data-driven teaching and data governance	Governance mechanism	Data governance	Data-driven decision making	L06/L07
OC008 ICT infrastructure and new infrastructure	Implementation condition	Infrastructure	Infrastructure coverage level	L01/L12/L19
OC010 Digital resources and content quality	Enabling factor	Resource construction	Digital resource construction	L04
OC011 Government policy and funding support	Driver factor	Policy environment	Policy and regulation support	L02/L16/L36
OC015 Regional digital equity and divide	Barrier factor	Social culture	Social culture and value orientation	L11/L19/L31
OC014 Parent participation and home''school collaboration	Implementation condition	Home''school collaboration	Parental digital literacy and participation	L04/L07/L30



03_Axial_Coding

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IV. Axial Coding (S2.3)

In the axial coding stage, conceptually similar open codes are grouped into secondary factor categories to reduce fragmentation, establish analytically meaningful clusters, and attach measurable indicators to each category.

Table S4. Secondary Factor Category System

PPTE Dimension	Secondary Category	Included KSFs
People	Teacher literacy	Teacher digital literacy; Teacher professional development support
	Teacher attitude	Willingness and attitude towards tech adoption
	Student literacy	Student information literacy; Student digital competency development
	Leadership	Administrator digital leadership; CIO system and information organization construction
Process	Strategic planning	Digital strategy and planning formulation; Phase division and task decomposition
	Project management	Project management and progress control
	Quality assurance	Quality assurance and continuous improvement
	Teaching application	Curriculum integration and teaching application; Teaching model innovation
	Culture construction	Digital culture construction
	Data governance	Data-driven decision making
Technology	Infrastructure	Infrastructure coverage level; Technology selection and platform integration

	System quality	System usability and accessibility; Child-friendliness focus; Data security and privacy protection
	Resource construction	Digital resource construction
Ecosystem	Policy environment	Policy and regulation support
	Resource guarantee	Funding and resource guarantee
	Social culture	Social culture and value orientation
	Home"Cschool collaboration	Parental digital literacy and participation
	Collaboration network	Multi-party collaboration network; Enterprise technical support and services



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V. Selective Coding (S2.4) – PPTE Framework

Integration Logic: Drawing on organizational change theory (PPT model), digital transformation literature (TOE framework, TAM model), and education digital maturity models, the 18 secondary categories and 27 KSFs are integrated upward into four core dimensions (People-7KSFs, Process-8KSFs, Technology-6KSFs, Ecosystem-6KSFs):

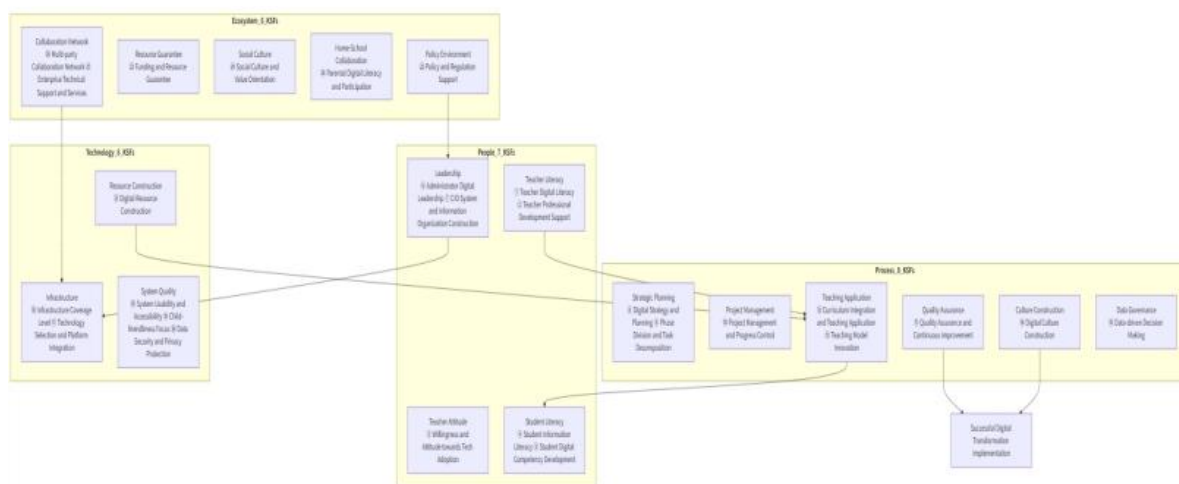


Figure S1. KSFs_PPTE Structural diagram

VI. KSF Measurement Logic (S2.5)

For each identified KSF, measurable indicators are synthesized from empirical studies to ensure operational clarity.

Table S5. KSF Measurement Logic

Indicator Type	Description	Examples
Quantitative indicators	Frequency, coverage, regression/path coefficients	Digital teaching frequency $\beta=0.262$; platform service $\beta=0.439$
Qualitative	Perception, readiness, mechanism	Perceived usefulness; organizational readiness;

descriptors	descriptions	governance connectivity
Configurational indicators	Conjunctural consistency, coverage	conditions, fsQCA core/peripheral conditions; consistency > 0.8

Examples of measures for “teachers’ digital competence” (synthesizing L06, L18, and L20):

1. Ability to search for, evaluate, and manage digital information (Digital Literacy Scale)
2. Proficiency in using digital instructional tools (TPACK / frequency of tool usage)
3. Integration of digital resources with curriculum objectives (observation of curriculum integration)
4. Frequency of technology-supported inquiry or collaborative learning (frequency of instructional implementation)
5. Willingness to engage in professional learning regarding emerging technologies (motivation for continuous learning)



04_27_PPTE_KSF_Measurement_and_Evidence_Matrix.csv.

Output: 04_27_PPTE_KSF_Measurement_and_Evidence_Matrix.csv.

VII. Factor Relationship Path Extraction (B.6)

Beyond KSFs, significant relationships evidenced in each empirical study are extracted and labeled by effect type:

Table S6. KSF Measurement Logic

Effect Type	Definition	Example from This Study
Direct Effect	A significantly affects B	Platform services → Application intention ($\beta=0.439$)
Mediating Effect	A → M → B; M acts as a transmitter	Leadership → Organizational commitment → School effectiveness (full mediation)
Moderating Effect	C alters the strength of A → B	School level moderates e-leadership path; region moderates literacy
Chain Mediation	A → M1 → M2 → B	Context → Trigger → Enablement → Transformation (90.06% indirect)
Configurational Effect	Multiple factors jointly sufficient for the outcome	TOE configurations H1–H4; satisfaction configurations H1–H3b
Sequential Path	Phased causal chain	Attitude → Intention → Usage behavior (western rural areas)

Path extraction fields: Path ID, source KSF, target KSF/outcome, effect type, mediator/moderator, effect size, method, literature ID.

Output: 31 validated factors paths. see the file



“05_27_PPTE_Validated_Paths_Summary.csv” .

05_27_PPTE_Validated_Paths_Summary.csv.