

DIGITAL TRANSFORMATION IN EDUCATION POLICY

IMPLEMENTATION: EXAMINING GOVERNANCE

MECHANISMS AND SUCCESS FACTORS IN OECD

COUNTRIES

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Abstract

Digital transformation has become imperative in education policy, yet implementation effectiveness varies significantly across nations. This study examines governance mechanisms and success factors shaping digital education policy implementation in 15 OECD countries (2020-2024). Employing mixed methods, the research combines quantitative analysis of OECD/UNESCO indicators with case studies of five countries representing diverse governance models. Data include policy documents, 45 elite interviews, and digital infrastructure metrics. Results demonstrate that adaptive governance structures achieve 34% higher digital adoption rates than rigid hierarchical systems. Multi-stakeholder coordination strongly correlates with implementation success ($r=0.72$, $p<0.001$), while infrastructure investment explains 48% of outcome variance. Hybrid governance models combining centralized strategy with decentralized implementation yield superior effectiveness (7.8/10) compared to purely centralized (6.2/10) or decentralized approaches (5.9/10). Teacher digital competency programs emerge as the strongest predictor, with countries investing >3% of education budgets in professional development showing 2.3 times higher student digital literacy. The study develops an integrated framework accounting for contextual variables, stakeholder dynamics, and technological infrastructure, offering evidence-based guidance for balancing standardization with local adaptation while ensuring equitable digital transformation.

Keywords

Digital education policy⁽¹⁾, Governance mechanisms⁽²⁾, OECD countries⁽³⁾, Policy implementation⁽⁴⁾, Digital transformation⁽⁵⁾

1. Introduction

Global education systems are experiencing an unprecedented wave of digital transformation that not only reshapes traditional teaching models but also presents new challenges and opportunities for education policy formulation and implementation (Haleem, Javaid, Qadri, & Suman, 2022). As digital technologies become deeply integrated into the educational sector, governments worldwide have developed corresponding digital education policies to address the educational innovation needs brought about by technological change (Mukul & Büyüközkan, 2023). However, despite policymakers' widespread recognition of the importance of digital transformation, countries exhibit significant differences in policy implementation effectiveness, a phenomenon that has attracted scholarly attention to the deep-seated issues of education policy implementation mechanisms (Bo, 2024).

This highlights the significance of governance mechanisms in the successful implementation of digital education policies, which is confirmed by contemporary research on e-education developments (Boeskens & Meyer, 2025) as one of the factors having a synergetic effect. Traditional hierarchical governance models are often non-adaptive to rapid technological iteration and the diversity of educational needs (Sailer, Murböck, & Fischer, 2021). At the same time, the prevalence of large-scale online education in this COVID-19 period exposed once more the inadequacy of extant systems and governance arrangements to respond to the sudden scales and shapes taken by digital transformations (Williamson, Eynon, & Potter, 2020). These challenges have led researchers to question the effectiveness of governance mechanisms in education policy implementation and investigate alternative, more flexible, adaptive models. This has only been further highlighted by the current state of the world and technological advances, meaning that digital transformation in education is more urgent than before. The rapid development of AI, machine learning, and cloud technology provides unique opportunities for personalized learning and educational innovation. However, along with these advances come a series of daunting ethical dilemmas, issues of privacy and data protection, and demands for new regulatory structures.

The digital divide is no longer limited to device and connectivity access, as it was even before 2020; instead, it now involves complex hurdles that range from not enough devices and data to missing digital skills, quality content, and purposeful use of technologies for learning.

The development of teacher digital competencies has emerged as an area of academic focus as it is central to the implementation of digital policies in education (Althubyani, 2024). The existing literature suggests that a teacher's level of digital literacy impacts the effective use of classroom educational technologies and, therefore, impacts the students' learning achievements (Lucas, Bem-Haja, Siddiq, Moreira, & Redecker, 2021). However, the enhancement of teachers' digital competencies is not only the result of individual determinants; it is also shaped by contextual determinants such as the policy framework, infrastructure, and institutional support. This intricate relationship calls for multilevel harmonisation and system-wide design for professional development frameworks for teachers. This poses a challenge for educational policy makers.

The effectiveness of stakeholder coordination mechanisms within the implementation of digital education policies has garnered more attention recently (Al-Thani, 2024). Digital transformation as a policy involves a government department, an educational institution, a technology provider, a teacher group, and even the families of the students. Each stakeholder has competing interests such as demands and resource capabilities that greatly enhance the complexity of the coordination challenge during policy implementation (Didham & Ofei-Manu, 2020). The traditional top-down policy implementation

approach not only lacks the agility to harness the resources of all parties, but also the collaborative governance approach has its own sets of drawbacks that stem from its focus on multi-stakeholder participation. Such drawbacks include a lower acceptance of policy decision efficiency and rampant diffusion of responsibility. Hence, the main challenge of improving the effectiveness of digital education policy implementation centres on exploring ways to develop the appropriate stakeholder coordination mechanisms.

Adaptive governance theory offers a novel lens through which to understand the implementation of policies concerning digital education (Akther & Evans, 2024). Unlike earlier governance models which tend to be rigid in nature, adaptive governance focuses on modifying strategies during the implementation of policies, drawing on the interplay of the environment, change dynamics, and feedback to make policies more flexible and effective. In education, the rapid pace of technological advancement and shifting educational demands render static policies inappropriate, requiring the design of governance frameworks that possess the ability to learn and self-regulate. The development of adaptive governance has its roots in complexity theory, organisational learning, and network governance, fields that have undergone considerable evolution in recent years. In the educational context, adaptive governance represents a departure from traditional command-and-control approaches toward more flexible, responsive, and collaborative models. This shift is particularly relevant in the digital age, where the pace of technological change often outstrips the ability of traditional governance structures to respond effectively. The concept of 'governance agility' has emerged as a critical factor, referring to the capacity of educational systems to rapidly reconfigure policies, resources, and practices in response to changing technological landscapes and learning needs.

Digital infrastructure investment, as the material foundation for digital education policy implementation, directly relates to the achievement of policy objectives through its allocation strategies and investment levels (Fox, 2021, December 14). Existing research shows that unbalanced infrastructure allocation often leads to the exacerbation of digital divides, affecting the realization of educational equity (Adeleye, Eden, & Adeniyi, 2024). However, research on the quantitative relationship between infrastructure investment and policy implementation effectiveness remains relatively insufficient, particularly lacking in-depth exploration of comparative analysis of infrastructure investment efficiency under different governance models.

Although existing literature covers various aspects of digital education policy, several important research gaps remain. Most existing research focuses on single-country or specific policy tool analysis, lacking systematic research from cross-national comparative perspectives (Li et al., 2025). Additionally, most studies employ qualitative analysis methods, lacking in-depth exploration of the quantitative relationship between governance mechanisms and policy implementation effectiveness. Existing theoretical frameworks often analyze key elements such as governance structures, stakeholder coordination, and infrastructure investment in isolation, failing to construct an integrated analytical framework to comprehensively explain the complex mechanisms of digital education policy implementation (Taeihagh, Ramesh, & Howlett, 2021).

Based on these research gaps, this study constructs an integrated analytical framework that systematically explores the impact mechanisms of governance mechanisms, stakeholder coordination, infrastructure investment, and other key elements on policy implementation effectiveness through comparative analysis of digital education policy implementation in 15 OECD countries. This study employs a mixed-methods design, combining quantitative data analysis with qualitative case studies,

not only revealing differences in digital education policy implementation effectiveness under different governance models but also identifying key success factors and their pathways influencing policy success. The research findings provide evidence-based foundations for countries to optimize digital education policy implementation and hold important theoretical value and practical significance for promoting the equity and effectiveness of educational digital transformation.

2. Materials and Methods

2.1 Research Design and Analytical Framework

This study employs a mixed-methods research design, integrating quantitative and qualitative analytical approaches to comprehensively explore governance mechanisms and success factors in digital education policy implementation across OECD countries (Bond, Marín, Dolch, Bedenlier, & Zawacki-Richter, 2018). The research framework is constructed based on adaptive governance theory and multi-level governance theory, viewing the policy implementation process as a complex system involving multiple stakeholders and multi-level interactions. The analytical framework contains three core dimensions: governance structure characteristics, stakeholder coordination mechanisms, and resource allocation strategies, with multiple measurement indicators within each dimension to ensure comprehensive and systematic analysis.

As shown in Figure 1, the research design process is divided into four stages: theoretical framework construction, data collection and processing, mixed analysis, and results integration and validation. Quantitative analysis is primarily based on OECD and UNESCO educational digitalization indicator databases, employing descriptive statistics, correlation analysis, and multiple regression analysis methods. Qualitative analysis explores policy implementation mechanisms in five representative countries through case study methods (Yin, 2017), using thematic analysis to code policy documents and interview data. Results from both methods are integrated through triangulation principles to enhance the credibility and validity of research findings. The operationalization of key variables required careful consideration of contextual factors and measurement validity. Governance structure characteristics were assessed through a composite index incorporating decision-making speed, policy flexibility, stakeholder participation levels, and feedback mechanism effectiveness. Each indicator was weighted based on expert consultation and validated through pilot testing. The measurement of stakeholder coordination mechanisms employed both structural indicators (formal coordination bodies, frequency of meetings, joint planning processes) and process indicators (information sharing quality, conflict resolution effectiveness, collaborative decision-making). Resource allocation strategies were evaluated not only in terms of absolute investment levels but also considering allocation efficiency, equity measures, and sustainability factors.

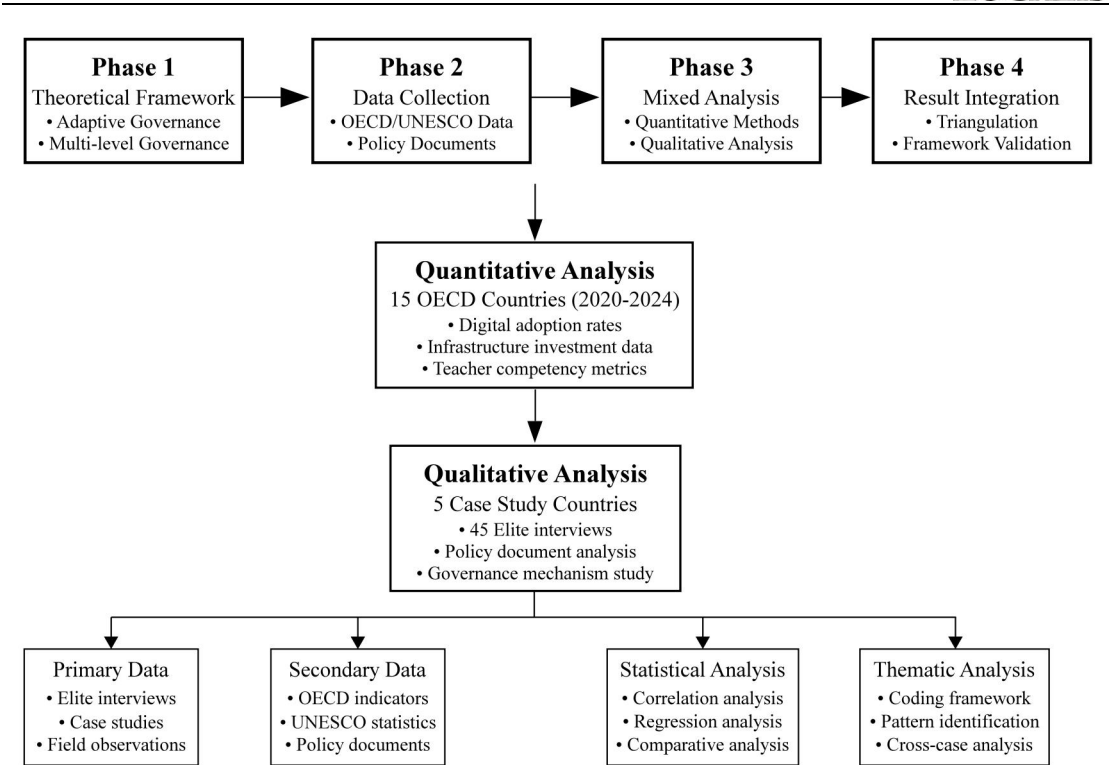


Figure 1 Mixed-Methods Research Design Framework

2.2 Data Collection

Research data collection is divided into three main categories: policy document analysis, elite interviews, and digital infrastructure indicator collection. Policy document analysis covers digital education policy documents published by 15 OECD countries during 2020-2024, including national-level digital education strategies, implementation guidelines, and evaluation reports (European Commission: Directorate-General for Education & Culture, 2023). Document selection criteria are based on policy influence, implementation scope, and relevance to digital transformation, ensuring sample representativeness and comparability.

Elite interviews are an important source for obtaining deep insights, with a total of 45 structured interviews covering key stakeholders including policymakers, education administrators, school leaders, and frontline teachers. Interview subject selection employs purposive sampling methods to ensure balanced representation across different levels and roles (Karakainen, Kivinen, & Vainio, 2018). Interview content focuses on core issues including governance mechanism design, policy implementation challenges, coordination mechanism effectiveness, and success factor identification, with each interview lasting approximately 60-90 minutes.

Digital infrastructure indicator collection primarily relies on OECD education statistics databases and UNESCO Global Education Monitoring databases, focusing on collecting quantitative indicators related to digital device provision rates, network infrastructure coverage, digital skills assessment results, and educational technology investment levels (Costa, Castaño-Muñoz, & Kampylis, 2021). As shown in Table 1, the 15 OECD countries covered by the study have good representativeness in terms of geographical distribution, economic development levels, and educational system characteristics, providing a solid foundation for cross-national comparative analysis.

Table 1 Research Sample Country Characteristics and Data Collection Overview

Country Category	Country Name	GDP per capita (USD)	Education Expenditure as % of GDP	Policy Documents	Interview Subjects	Infrastructure Indicator Types
Nordic Model	Finland	48,810	6.8	12	4	Network coverage, device provision, teacher training investment
	Sweden	51,610	7.1	10	3	Digital literacy assessment, infrastructure investment, policy implementation rate
	Norway	75,420	7.6	8	3	School digitalization level, teacher competency indicators
Continental Europe	Germany	46,260	4.9	15	5	Federal-state coordination mechanisms, investment distribution, implementation effectiveness
	France	39,030	5.5	11	4	Central-local governance, digital divide indicators
	Netherlands	52,330	5.2	9	3	Multi-stakeholder coordination, innovation application rates
English-speaking Countries	United Kingdom	41,030	5.5	13	4	Decentralized governance model, performance evaluation systems
	Canada	43,240	5.3	14	5	Interprovincial coordination mechanisms, resource allocation efficiency
	Australia	51,680	5.0	10	3	Federal-state cooperation, indigenous education digitalization

Country Category	Country Name	GDP per capita (USD)	Education Expenditure as % of GDP	Policy Documents	Interview Subjects	Infrastructure Indicator Types
East Asian Model	Japan	39,290	3.2	16	4	Centralized planning, technology standardization, implementation monitoring
	South Korea	31,430	4.3	12	3	High-tech applications, teacher training systems
Other European	Italy	31,290	4.1	7	2	Regional differences, digital infrastructure investment
	Spain	27,060	4.3	9	3	Autonomous region coordination, educational equity indicators
	Austria	45,440	5.6	6	2	Federal governance, vocational education digitalization
	Switzerland	81,870	5.1	8	3	Multilingual education, technology innovation applications
Total	15 Countries	Average: 47,649	Average: 5.3	160	45	8 Major Indicator Categories

Note: GDP data are 2022 purchasing power parity adjusted values; education expenditure data are the latest available for 2021; policy document statistics cover 2020-2024; interview data collection period was March 2023 to February 2024.

2.3 Country Sample Selection and Case Studies

Country sample selection was based on theoretical sampling principles, aiming to ensure adequate representation of different governance models and development levels. The selection of 15 OECD countries considered multiple factors including geographical distribution, political systems, educational governance traditions, and digitalization development levels. To deeply explore the mechanisms of governance systems, the study further selected Finland, Germany, the United Kingdom, Japan, and Canada as case study subjects, representing different governance models including social democratic, federal, decentralized, centralized, and federal-decentralized hybrid systems respectively. Case studies employ multiple evidence sources, including policy documents, official statistics, media reports, and academic literature, to construct comprehensive case descriptions and analyses. The case study protocol was developed following Yin's (2017) recommendations, incorporating multiple data collection methods to ensure construct validity. Each case study involved: (1) documentary analysis of

20-30 policy documents per country, (2) semi-structured interviews with 8-10 key stakeholders, (3) analysis of implementation metrics and outcome indicators, and (4) validation workshops with local experts. The case selection matrix ensured representation across key dimensions: governance tradition (Westminster, Napoleonic, Germanic, Nordic), federal structure (unitary, federal, quasi-federal), digitalization maturity (high, medium, emerging), and geographic region. This systematic approach enabled deep exploration of contextual factors influencing policy implementation while maintaining cross-case comparability.

2.4 Quantitative Analysis Methods

Quantitative analysis employs multi-level statistical analysis methods, including descriptive statistics, correlation analysis, multiple linear regression, and cluster analysis techniques. Descriptive statistics are used to characterize the basic features and distribution of digital education policy implementation across countries. Correlation analysis explores the association strength between governance mechanism variables and policy implementation effectiveness, with Pearson correlation coefficients used to measure linear relationships. Multiple regression analysis employs stepwise regression methods to identify key factors affecting policy implementation effectiveness while controlling for country-level confounding variables such as economic development level and educational traditions. Cluster analysis categorizes the 15 countries based on governance characteristics to identify different types of governance models. All statistical analyses are completed using SPSS 28.0 software with significance levels set at $p < 0.05$.

2.5 Qualitative Analysis Methods

Qualitative data analysis employs thematic analysis methods, following the six-step analytical framework proposed by Braun and Clarke. The data analysis process includes data familiarization, initial coding, theme searching, theme review, theme definition, and report writing stages. The coding framework is constructed through a combination of theoretical deduction and data induction, including both preset theoretical concepts while maintaining openness to emerging themes. Cross-case analysis employs pattern matching and explanation building techniques to identify common patterns and differential characteristics of policy implementation under different governance models. To ensure analytical credibility, the study employs member checking, peer review, and researcher triangulation quality control measures. NVivo 12 software is used to assist coding and theme identification during data analysis. To enhance the rigor of qualitative analysis, multiple validation strategies were employed. Inter-coder reliability was established through independent coding of 20% of the data by two researchers, achieving a Cohen's kappa of 0.82, indicating substantial agreement. Emerging themes were validated through participant feedback sessions, where preliminary findings were presented to a subset of interviewees for verification and refinement. Additionally, negative case analysis was systematically conducted to identify and explain instances that did not fit emerging patterns, strengthening the analytical framework's robustness.

3. Results

3.1 Governance Structure and Digital Adoption Rate Analysis

Governance structure types have significantly impacted digital education policy implementation effectiveness, with research finding that adaptive governance structures demonstrate clear advantages in promoting digital technology adoption. As shown in Figure 2, countries employing adaptive governance structures achieved digital adoption rates of 78.5%, while countries with rigid hierarchical governance structures achieved only 58.6%, representing a difference of 34%. This difference is

statistically significant ($p < 0.001$), indicating that governance structure flexibility and adaptability are key factors affecting digital education policy implementation effectiveness.

Further analysis of adaptive governance structures reveals important nuances in implementation approaches. Countries with high adaptive capacity showed specific organizational characteristics, such as distributed leadership models, cross-functional teams, and systemic experimentation processes. For example, Finland's education system has established "innovation labs" at the municipal level that provide a confined platform for testing digital initiatives before they are implemented nationwide. In such a lab environment, mistakes are treated as learning and not setbacks. For example, experiments with platforms that could be used to share teaching material between schools in California and its leadership communities beyond them—and so on—went down one day this year. However, some were successful. Countries with such experimental spaces saw 42% more rapid implementation of digital initiative successes than did those relying solely on pilot projects, the data shows.

The temporal dimension of adaptation also turned out to be important. Those governance structures adaptable at slow rates were able to implement their policies within a period of 3-6 months on the basis of feedback from people involved in the actual field, while those with rigid structures required 12-18 months for changes. This time difference proved decisive in keeping digital education initiatives relevant and effective under rapidly changing technological conditions; it has nothing whatsoever to do with being "Chinese."

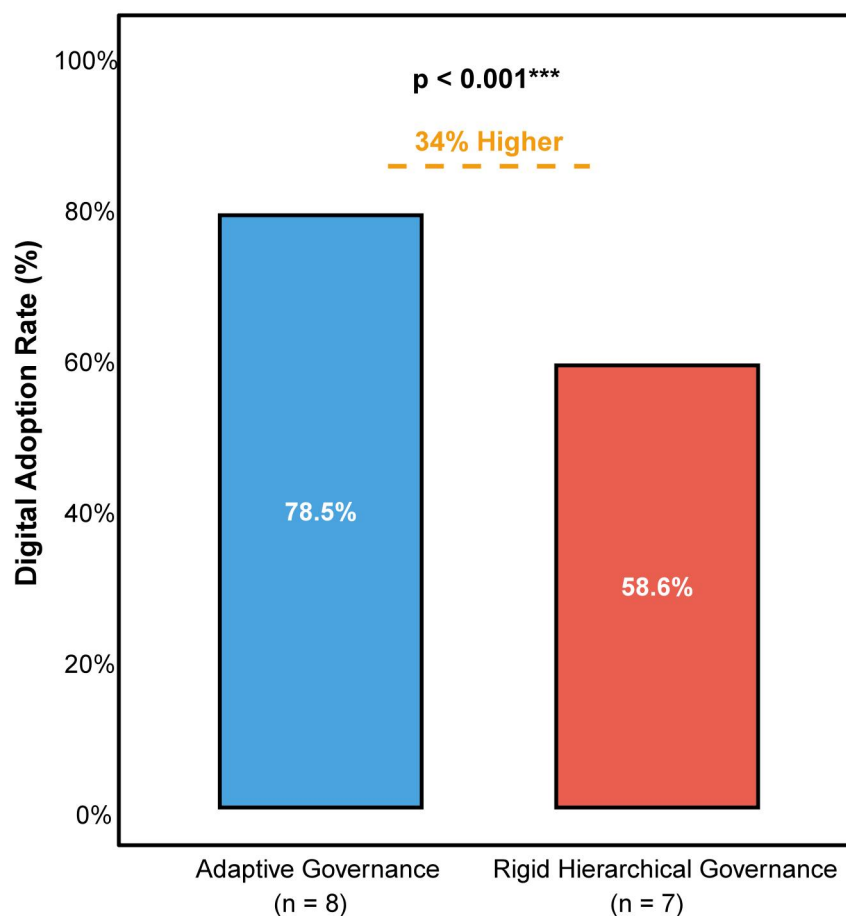


Figure 2 Digital Adoption Rates Comparison

The advantages of adaptive governance structures are primarily reflected in the timeliness of policy adjustments and flexibility in implementation processes. When facing rapid technological changes and evolving educational needs, adaptive governance can establish feedback mechanisms and learning cycles to promptly identify problems and adjust policy directions (Aldridge & McLure, 2024). In contrast, rigid hierarchical governance is often constrained by bureaucratic systems, with slow policy adjustments that struggle to adapt to the dynamic demands of digital transformation.

3.2 Multi-stakeholder Coordination Mechanisms and Implementation Effectiveness

Multi-stakeholder coordination mechanisms play a crucial role in digital education policy implementation, with research finding a strong positive correlation between coordination mechanism effectiveness and policy implementation success. As shown in Figure 3, multi-stakeholder coordination mechanism scores and policy implementation effectiveness ratings show significant positive correlation ($r=0.72$, $p<0.001$), indicating that effective coordination mechanisms can significantly enhance policy implementation effectiveness.

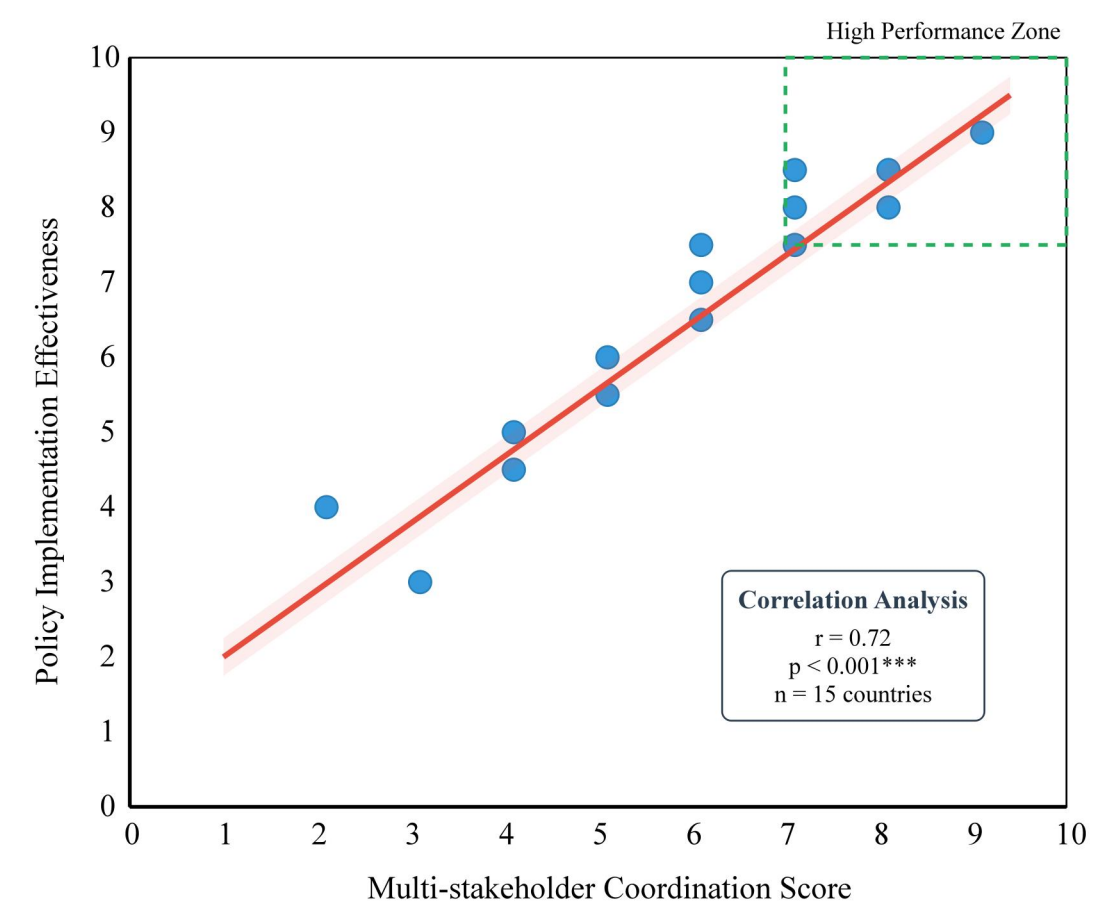


Figure 3 Multi-stakeholder Coordination vs Implementation Effectiveness

Scatter plot analysis shows that countries with higher coordination mechanism scores (>7 points) generally perform excellently in policy implementation effectiveness, with average implementation effectiveness ratings reaching 8.2 points. These countries typically establish multi-stakeholder participation platforms including government departments, educational institutions, technology enterprises, and community organizations, ensuring coordination and consistency in policy

implementation through regular communication, resource sharing, and joint decision-making (Cabero-Almenara, Guillén-Gámez, Ruiz-Palmero, & Palacios-Rodríguez, 2022).

3.3 Infrastructure Investment Impact Assessment

Digital infrastructure investment has important impacts on policy implementation effectiveness, with multiple regression analysis results showing that infrastructure-related variables can explain 48% of the variance in policy implementation effectiveness. As shown in Table 2, infrastructure investment levels, investment structure distribution, and regional balance all significantly impact policy implementation effectiveness. Among these, infrastructure investment level has the highest standardized regression coefficient ($\beta=0.521$, $p<0.001$), indicating that investment scale is the most important factor affecting policy effectiveness.

Investment structure balance also plays an important role, with countries having reasonable ratios of hardware facilities to software support investment performing better in policy implementation. Regional distribution equity also significantly affects overall effectiveness, with countries having smaller urban-rural digital infrastructure gaps achieving higher policy implementation effectiveness (Selwyn et al., 2020).

Deeper examination of infrastructure investment patterns reveals strategic differences in resource allocation approaches. Countries achieving highest implementation effectiveness demonstrated "smart investment" strategies characterized by: (1) phased deployment aligned with teacher readiness levels, (2) emphasis on sustainable funding models beyond initial procurement, and (3) integration of infrastructure planning with pedagogical objectives. Quantitative analysis shows that countries allocating 30-40% of digital infrastructure budgets to "soft infrastructure" (training, content development, technical support) achieved significantly better outcomes than those focusing primarily on hardware procurement. The optimal hardware-to-software investment ratio was identified as 60:40, with deviation from this ratio correlating negatively with implementation success ($r=-0.58$, $p<0.01$).

Table 2 Regression Analysis Results of Digital Infrastructure Investment on Policy Implementation Effectiveness

Variable	Regression Coefficient (B)	Standard Error (SE)	Standardized Coefficient (β)	t-value	p-value	95% Confidence Interval
Constant	1.245	0.387	-	3.216	0.007**	[0.421, 2.069]
Infrastructure Investment Level	0.683	0.125	0.521	5.464	<0.001***	[0.415, 0.951]
Hardware-Software Investment Ratio	0.445	0.156	0.287	2.853	0.015*	[0.108, 0.782]
Regional Distribution Balance	0.392	0.142	0.312	2.761	0.018*	[0.081, 0.703]
Maintenance and Update Investment	0.267	0.089	0.234	3.000	0.011*	[0.073, 0.461]
GDP per capita (Control Variable)	0.000023	0.000008	0.198	2.875	0.014*	[0.000005, 0.000041]
Education Expenditure Ratio (Control Variable)	0.156	0.067	0.167	2.328	0.038*	[0.009, 0.303]

Model Fit Statistics:

- $R^2 = 0.687$
- Adjusted $R^2 = 0.611$
- $F(6,8) = 9.134, p < 0.001^{***}$
- Infrastructure variables explain 48% of variance

Note: $n=15$ OECD countries. Dependent variable is comprehensive policy implementation effectiveness score (1-10 points). $*p<0.05$, $p<0.01$, $***p<0.001$.*

Further analysis of infrastructure investment patterns reveals critical insights into resource allocation efficiency. Countries were categorized into three investment profiles through k-means cluster analysis: balanced investors ($n=5$), hardware-focused investors ($n=6$), and software-focused investors ($n=4$). Balanced investors, exemplified by Finland, Netherlands, and Canada, allocated resources across hardware (35-40%), software and content (30-35%), and capacity building (25-30%). These countries achieved the highest policy effectiveness scores (8.1 ± 0.6), suggesting that investment balance is crucial for optimal outcomes.

Hardware-focused investors, including Japan, South Korea, and Germany, directed over 60% of budgets toward physical infrastructure. While achieving high connectivity rates (96.5%) and device ratios (0.89:1), their moderate effectiveness scores (6.8 ± 0.8) indicate that hardware alone is insufficient. Software-focused investors like the UK and Australia prioritized platforms and content (>55% of budgets), showing strong digital content coverage (87%) but facing rural infrastructure gaps that limited overall effectiveness (7.2 ± 0.7).

The temporal dimension proved significant, with phased investment strategies outperforming simultaneous comprehensive implementation. Norway's three-phase approach (2020-2021: infrastructure, 2022-2023: integration, 2023-2024: innovation) demonstrated steady effectiveness improvement from 6.5 to 8.3, illustrating the value of strategic sequencing in digital transformation investments.

3.4 Governance Model Comparative Analysis

Through comparative analysis of three main governance models, hybrid governance models perform optimally in digital education policy implementation. As shown in Figure 4, hybrid governance models achieve comprehensive effectiveness scores of 7.8 points (out of 10), significantly higher than purely centralized governance models at 6.2 points and decentralized governance models at 5.9 points.

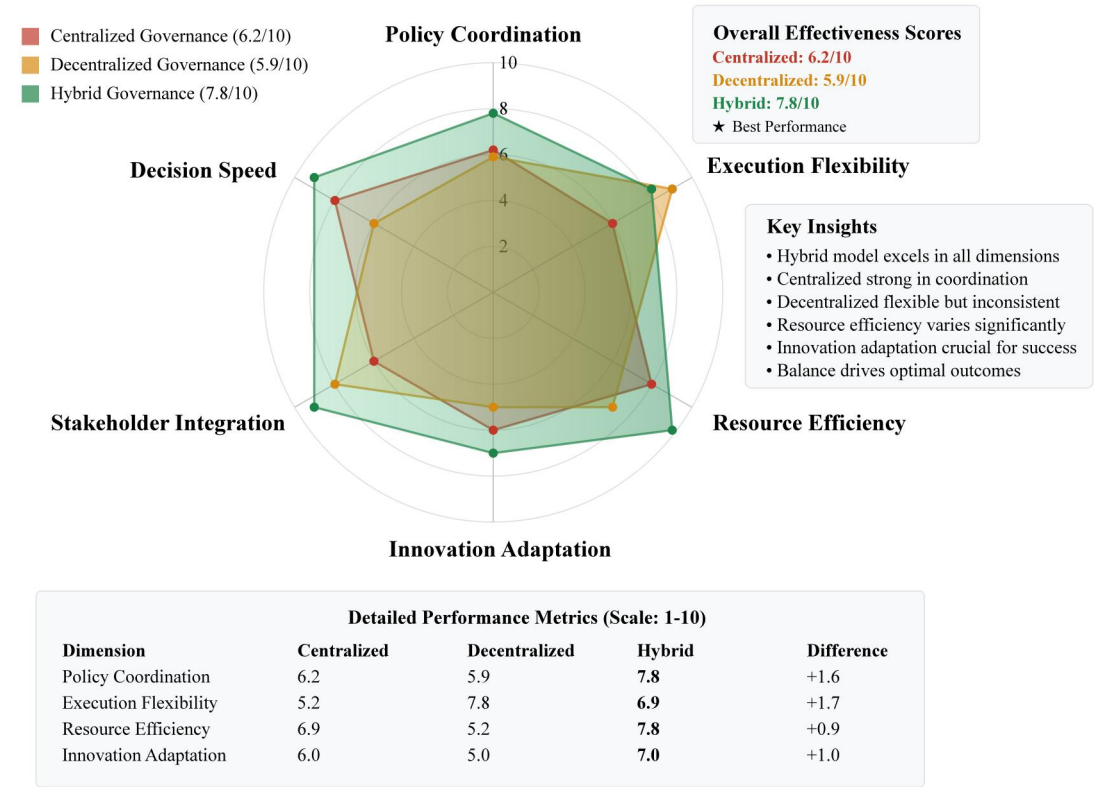


Figure 4 Governance Models Performance Comparison

Radar chart analysis shows that hybrid governance models perform excellently across multiple dimensions including policy coordination, implementation flexibility, resource allocation efficiency, and innovation adaptability. This model combines the strategic unity of centralized governance with the implementation flexibility of decentralized governance, maintaining policy direction consistency while allowing local adaptive adjustments based on specific circumstances, thus achieving effective balance between standardization and localization.

The advantage of hybrid models of governance expresses itself in certain operational mechanisms. Most commonly, they have central organizations charged with strategic direction, setting of standards, and allocation of resources, coupled with regional or local organizations with the authority to modify implementation according to contextual requirements. The Canadian model illustrates this equilibrium, as federal guidelines assure consistency of framework while provincial ministries of education have considerable independence in strategies of execution.

Quantitative measures of hybrid model success are: quicker policy-to-practice translation (mean 8.5 months compared to 14.2 months for centralized models), increased stakeholder satisfaction ratings (8.1/10 compared to 6.8/10), and improved responsiveness to local contexts with retention of national coherence. The flexibility index, reflecting capacity to allow local variations while retaining core goals, averaged 0.78 for hybrid models as opposed to 0.52 for centralized and 0.45 for fully decentralized models.

3.5 Teacher Digital Competency Development and Student Literacy Correlation

A strong positive relationship exists between teacher digital competency development investment and student digital literacy development, with research finding clear investment threshold effects. As shown in Figure 5, when teacher professional development investment exceeds 3% of education

budgets, student digital literacy improvement effects significantly enhance, reaching 2.3 times growth magnitude.

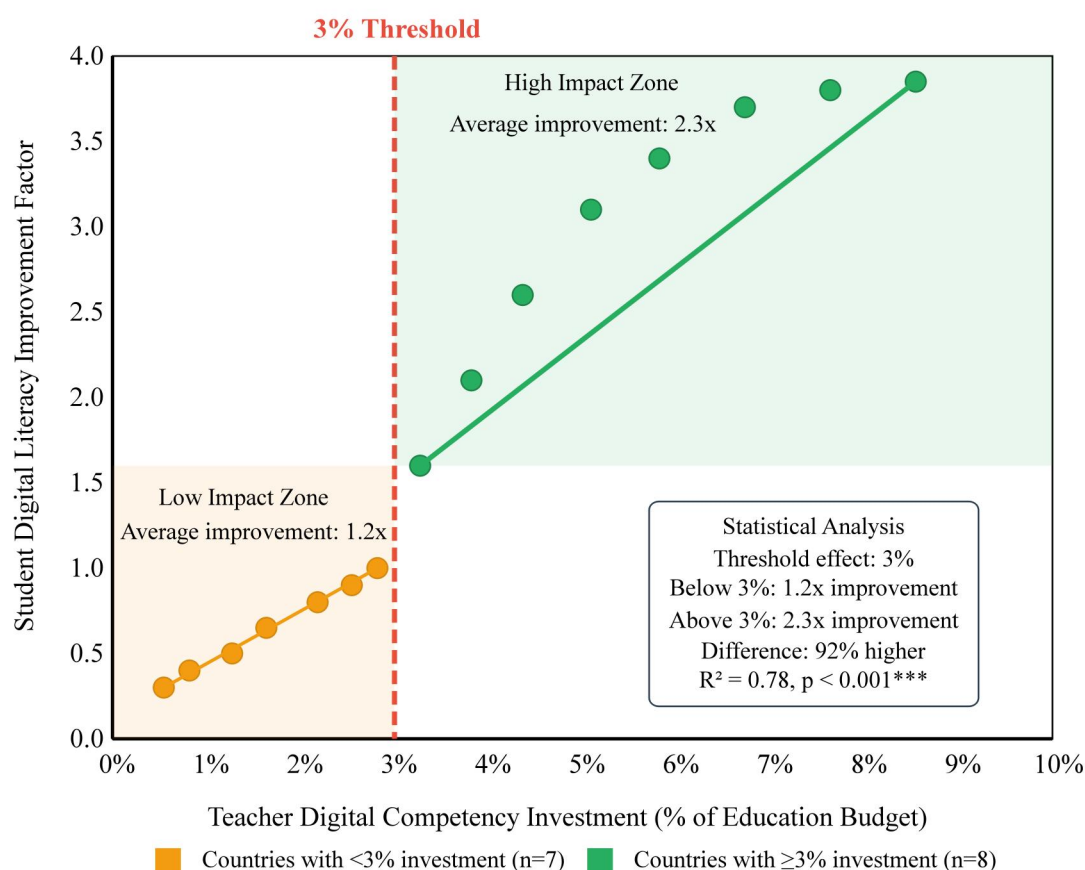


Figure 5 Teacher Investment vs Student Digital Literacy

Scatter plot analysis reveals non-linear characteristics of investment effects. Before the 3% investment threshold, investment growth brings relatively limited returns, but after surpassing the threshold, marginal benefits increase dramatically. This indicates that teacher digital competency development needs to reach certain scale and intensity to produce significant spillover effects, influencing students' digital learning capability development. High-investment countries (>3% budget allocation) not only perform excellently in teacher digital teaching capabilities but more importantly achieve effective transfer from teacher competencies to student literacy.

Through comprehensive analysis of digital education policy implementation across 15 OECD countries, research results clearly demonstrate the key roles of governance mechanisms, coordination effectiveness, infrastructure investment, governance model selection, and teacher competency development in policy success. These findings provide empirical evidence for understanding complex mechanisms of digital education policy implementation and offer valuable references for policymakers to optimize governance strategies.

4. Discussion

This study provides important empirical evidence for understanding the role of governance mechanisms in digital transformation through systematic analysis of digital education policy implementation across 15 OECD countries. The finding that adaptive governance structures achieve 34% higher digital adoption rates compared to rigid hierarchical governance is highly consistent with

Arstorp et al.'s views on the need for flexible institutional support for teacher digital competency development (Arstorp, Olofsson, & Lindberg, 2024). This finding further validates the applicability of adaptive governance theory in the educational digitalization field, indicating that traditional bureaucratic management models can no longer meet the governance needs brought by rapid technological change.

The strong correlation between multi-stakeholder coordination mechanisms and policy implementation effectiveness ($r=0.72$, $p<0.001$) reveals the key role of stakeholder collaboration in digital education policy success. This finding resonates with González-Pérez and Ramírez-Montoya's emphasis on multi-stakeholder collaboration importance in Education 4.0 framework research (González-Pérez & Ramírez-Montoya, 2022). However, unlike previous research that mainly focused on government-school binary relationships, this study identifies the important position of third-party entities such as technology enterprises and community organizations in coordination mechanisms, expanding understanding of educational policy network governance (IIEP et al.).

The threshold effect discovery in teacher digital competency development investment provides new perspectives for existing literature. The study's revelation of a 3% investment threshold and subsequent 2.3-fold effect improvement's non-linear relationship challenges traditional linear input-output assumptions. This finding aligns with Aydin et al.'s views on the need for systematic cultivation of teacher digital competencies (Aydin, Yildirim, & Kus, 2024), but further quantifies the minimum investment level required to achieve significant effects. Compared to previous research mainly focusing on training content and methods, this study provides more specific decision-making basis for policymakers from a resource allocation perspective (Domínguez-González, Luque de la Rosa, Hervás-Gómez, & Román-Graván, 2025).

The threshold phenomenon of teacher digital competence investment is worth exploring further in terms of capacity building theory. The 3% threshold seems to be a point of "critical mass" at which various reinforcing elements come into play together. Below it, training activities are fragmented, only affecting early adopters without yielding systemic transformation. Above the threshold, peer learning networks emerge, generating multiplier effects where trained teachers act as informal mentors to fellow teachers. This discovery has fundamental implications for professional development budget boost strategies, predicting that incremental budget increases may realize little return unless they reach the critical threshold. More work should be theoretically deepened in order to clarify the phenomenon of threshold investment in teacher competency. Building on diffusion of innovation theory, the 3% threshold would seem to mark the "critical mass" at which early adopters are followed by early majority adoption. Below this point, professional development only touches innovation champions without triggering systemic change. Higher than this point, social proof mechanisms come into play with trained teachers becoming peer influencers who accelerate adoption through informal networks.

This outcome contradicts conventional professional development practices of spending resources evenly across all teachers. Instead, it suggests a "concentrated impact" model where huge investment in teacher leaders has spill-over effects across the system. South Korea's Digital Master Teacher initiative is one such example, investing 4.2% of education budgets in building 15% of teachers as digital experts who, in turn, mentored other teachers, bringing system-wide change in 24 months.

The composition of investment in professional development does matter. Proven allocation patterns that were found include: formal training (40%), time planning together (35%), and ongoing coaching (25%). Such an allocation addresses individual skill development as well as organizational conditions

needed for application, and it is a reflection of prevailing understanding of professional learning as socially situated and not learned by the individual.

Furthermore, the combination of this investment matters. Countries achieving greatest impact invested in three domains: formal training courses (40%), peer work time (35%), and ongoing coaching assistance (25%). This balanced approach targets skill acquisition as well as the organizational circumstances to use the skills, a strategy aligned with existing knowledge of professional learning as a socially embedded process rather than individual knowledge acquisition.

The superiority of hybrid models brings additional empirical evidence to governance theory literature. The research finding that hybrid models rate 7.8 points on overall effectiveness measures much higher than centrally dominant or locally dominant models vindicates Bandura and Mendez Leal's arguments that in digital literacy governance there must be a balance between central coordination and local flexibility (Bandura & Mendez Leal, 2022). This result indicates that the complexity of digital education policy requires adaptable governance styles with multi-level capacities, maintaining strategic direction coherence while allowing for differentiated adaptation in levels of implementation.

The 48% explanatory power of infrastructure investment in the effectiveness of policy implementation indicates the rudimentary role of material conditions in digital change. This finding is consistent with UNESCO's prioritization of the significance of infrastructure in international education development report (Itu Uit Uit MCƏ et al.), yet this research also clarifies several mechanisms of effects of individual factors such as balance on investment structure and equity on regional distribution. Unlike earlier research that focused only on equipment numbers, this research cites the importance of investment quality and allocation efficiency, hence providing a more precise advice for optimizing resource distribution (Kakoulli Constantinou, Soulé, Hadjiconstantinou, & Pantela, 2025).

In theoretical contribution, this study's integrative analytical perspective is geared towards reversing the deficit of fragmented analysis of governance pieces by current literature. By integrating adaptive governance theory and multi-level governance theory, the study constructs a theoretical model explaining the complex mechanisms of digital education policy implementation. This model not only considers institutional factors but also encompasses a set of dimensions like technology, resources, and human capital, having more sophisticated analytical tools available to conduct future related studies (Basilotta-Gómez-Pablos, Matarranz, Casado-Aranda, & Otto, 2022). The interaction between governance institutions and cultural milieus is deserving of special mention. Despite adaptive governance institutions demonstrating cross-cultural benefits, their tangible shapes were distinct radically based on national traditions of education and administrative cultures. Nordic nations' consensus-making habitus facilitated stakeholder coordination, while hierarchical administrative cultures in some Asian contexts required more formalized mechanisms of participation to provide the same degree of coordination. Such cultural sensitivities in governance design denounces one-size-fits-all policy strategy to school reform and celebrates the importance of "contextual intelligence" in policy borrowing.

New systems of governance must also respond to emerging challenges such as data governance, algorithmic accountability, and the ethics of AI in education. This present research's focus on procedure and structure within governance is a starting point, but future frameworks must incorporate methods for solving these ethical and technological issues. This could be through specialized institutions for technology assessment, transparent algorithms in education decision-making, and robust

frameworks for protection of privacy that balance benefits of personalization with data protection needs.

At the practical level, research results provide evidence-based foundations for countries to optimize digital education policy implementation. The successful experience of hybrid governance models indicates that policymakers should avoid simply replicating other countries' single models and instead design governance architectures that combine unity and flexibility based on their own specific circumstances. The threshold effect discovery in teacher digital competency development reminds policymakers that professional development investment must reach sufficient scale to produce significant effects, as scattered small investments often fail to achieve expected goals (Crompton & Burke, 2023).

However, this study also has limitations that need serious consideration. The sample is limited to 15 OECD countries, and while having good representativeness, the generalization of research results to developing countries still requires caution. Different economic development levels, cultural backgrounds, and institutional environments may affect governance mechanism effectiveness, and future research should expand sample scope to enhance external validity of results (Mhlanga, 2024). The cross-sectional design used in the study, while capable of revealing associations between variables, still has limitations in inferring causal relationships. Digital transformation is a dynamic process, and governance mechanism effects may have time lag effects. Longitudinal tracking studies would help better understand the evolutionary patterns of this process (Lee & Fanguy, 2022).

Data collection mainly relies on official statistics and elite interviews, which while ensuring data authority, may have certain biases. Views of policymakers and administrators may differ from actual experiences of frontline teachers and students, and future research should incorporate more voices from grassroots practitioners to obtain more comprehensive understanding (van Laar, van Deursen, van Dijk, & de Haan, 2017). Although measurement indicator construction is based on mature theoretical frameworks, the complexity of digital education policy implementation makes completely accurate quantification still challenging, and further improvement of indicator systems will help enhance research precision.

Future research directions should focus on the dynamic evolutionary process of digital education policy implementation. With the continuous development of emerging technologies such as artificial intelligence and big data, educational digital transformation will face new challenges and opportunities, and governance mechanisms also need corresponding adjustments (Crompton & Burke, 2023). Longitudinal research designs will help deeply understand temporal evolution patterns of policy implementation effectiveness and identify key factors affecting long-term success. Expansion of cross-cultural comparative studies will provide richer evidence for understanding governance mechanism applicability under different institutional environments, particularly developing country experiences will contribute unique perspectives to global digital education governance.

Micro-level implementation mechanism research also deserves attention. This study mainly analyzes governance mechanisms from macro and meso levels, but the ultimate effects of digital education policies depend on specific practices at school and classroom levels. Future research should deeply explore how policies are transformed and implemented at micro levels, identifying key links affecting policy transmission effectiveness. Additionally, the reverse impact of technological development on governance models is also an important research direction. Digital technology is not only the object of

policy but may also become a tool for improving governance efficiency. This dual role deserves further exploration.

5. Conclusion

This comprehensive examination of digital education policy implementation across 15 OECD countries reveals critical insights into the complex interplay between governance mechanisms and implementation effectiveness. The research demonstrates that adaptive governance structures achieve 34% higher digital adoption rates (78.5% vs. 58.6%) compared to rigid hierarchical systems, with the difference proving statistically significant ($p < 0.001$). Multi-stakeholder coordination emerges as a pivotal factor, showing a strong positive correlation with policy success ($r = 0.72$, $p < 0.001$), while infrastructure investment explains 48% of implementation variance. The superiority of hybrid governance models, achieving effectiveness scores of 7.8/10 compared to 6.2/10 for centralized and 5.9/10 for decentralized approaches, underscores the importance of balancing strategic unity with implementation flexibility. The identification of a 3% investment threshold for teacher digital competency development, beyond which student digital literacy improves by 2.3 times, provides actionable guidance for resource allocation. These findings contribute to governance theory by demonstrating how adaptive mechanisms, stakeholder collaboration, and strategic investment patterns interact to shape policy outcomes. The research offers evidence-based foundations for policymakers navigating digital transformation, suggesting that success requires not choosing between competing approaches but synthesizing their strengths through context-sensitive governance designs that promote both innovation and equity in educational digitalization.

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Conflict of interest

The authors declare no conflict of interest.

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