

“Digital transformation of education in Ukraine: A methodological framework for integrated assessment”

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DIGITAL TRANSFORMATION OF EDUCATION IN UKRAINE: A METHODOLOGICAL FRAMEWORK FOR INTEGRATED ASSESSMENT

Abstract

Digital transformation has become a strategic prerequisite for improving the quality, accessibility, resilience, and competitiveness of education systems, creating a need for a coherent framework to integrate and assess heterogeneous evidence, particularly in Ukraine under wartime conditions. The purpose of this study is to develop and substantiate a methodological framework for the integrated assessment of digital transformation in education in Ukraine by systematizing its key determinants and establishing a conceptual basis for the Integral Digital Transformation Index of Education. The study employs the synthesis of international and national evidence, comparative analysis of existing assessment approaches, conceptual modeling, and a systems approach to organize complementary evidence according to its analytical level and methodological role. The study proposes a three-stage methodological architecture comprising the identification, classification, and conceptual grouping of potential indicators; a conceptual Delphi-based procedure for expert assessment and weighting; and subsequent integral aggregation for the future calculation of the Integral Digital Transformation Index of Education. The architecture distinguishes four interconnected determinants (digital infrastructure, digital competencies, digital educational resources and technologies, and digital potential for innovative development) and differentiates education-specific indicators from broader contextual and diagnostic evidence. Thus, the proposed concept provides a transparent, reproducible, and war-conditions-sensitive methodological framework and requires further empirical testing and validation for future implementation. In particular, future research should determine the final set of indicators, implement the Delphi procedure, establish empirically derived weighting coefficients, perform integral aggregation, and assess the reliability, sensitivity, stability, and temporal comparability of the resulting Integral Digital Transformation Index of Education.

Keywords

education, digital transformation, assessment, determinants, competencies, infrastructure, methodology, framework, Ukraine

JEL Classification

I21, O33, C43, I28

INTRODUCTION

Digital transformation has become an important driver of changes in education systems, affecting the quality and accessibility of education, institutional resilience, learning environments, governance, and the development of digital competencies. The rapid diffusion of digital platforms, cloud technologies, artificial intelligence, and other digital solutions has expanded the technological possibilities of education while simultaneously increasing the requirements for institutional capacity, human competencies, organizational adaptation, and innovation. Consequently, digital transformation is not merely the adoption of individual technologies but a multidimensional process involving interconnected technological, human, institutional, organizational, and innovation-related changes.

For Ukraine, the importance of digital transformation has increased substantially under the conditions of full-scale war. Digital technologies have supported the continuity of educational processes, facilitated remote and blended learning, and contributed to the resilience of educational institutions and learners amid disruptions to physical infrastructure and territorial accessibility. At the same time, digital transformation is closely connected with national education policy, European integration, human capital development, and the recovery and modernization of the education system. These circumstances increase the need for reliable, systematically organized evidence to support monitoring of digital transformation and inform strategic decision-making in education.

However, the evidence currently available for assessing digital transformation remains fragmented. International composite indices, national statistics, education-specific assessment instruments, analytical reports, surveys, and regional indicators measure different aspects of digital development at different analytical levels and according to different methodological principles. Broader indices provide important information about the technological, human-capital, innovation, and institutional environment in which education systems operate, whereas education-specific indicators capture more directly the conditions and practices of digitalization in education. Regional indicators additionally reveal territorial differences but may be affected by unequal data coverage, displacement, occupation, disruptions in statistical reporting, and other wartime conditions. Consequently, these sources cannot be treated as directly interchangeable or aggregated without an explicit methodological architecture that distinguishes their analytical roles.

This creates a scientific problem concerning the absence of a coherent methodological framework for organizing heterogeneous evidence and integrating complementary assessment approaches in the context of digital transformation of education. The challenge is not simply to identify additional indicators, but to establish a theoretically grounded structure that distinguishes education-specific assessment components from broader contextual and diagnostic evidence and provides a transparent sequence for their potential integration. Such an architecture is particularly important for Ukraine, where wartime conditions introduce additional requirements concerning territorial coverage, data comparability, and interpretation.

Addressing this problem provides a methodological basis for the future empirical operationalization of an integrated assessment of digital transformation in education. Such an approach can support the systematic organization of relevant evidence, the prospective application of expert judgment and weighting procedures, and the subsequent calculation and validation of the Integral Digital Transformation Index of Education. This methodological basis may strengthen the coherence, transparency, and reproducibility of future assessments while preserving the complementary role of existing international indices, national monitoring systems, and education-specific assessment instruments.

Accordingly, the purpose of this study is to develop and substantiate a methodological framework for the integrated assessment of digital transformation of education in Ukraine by systematizing its key determinants, organizing complementary sources of evidence within a coherent assessment architecture, and establishing a methodological foundation for the future empirical operationalization of the Integral Digital Transformation Index of Education.

1. THEORETICAL BASIS

Theoretical understanding of digital transformation in education has evolved from technology-oriented interpretations toward multidimensional perspectives encompassing infrastructure, gov-

ernance, human capital, institutional capabilities, and innovation. Existing studies and international assessment initiatives provide important evidence on these dimensions but approach them through different conceptual and methodological lenses. As a result, no single framework fully ex-

plains how these complementary dimensions can be organized within a coherent assessment architecture for education.

1.1. Digital transformation as a multidimensional educational phenomenon

Research on digital transformation of education has expanded considerably over the past decade, reflecting its growing importance for educational quality, institutional resilience, innovation, and strategic governance (Lugovyi et al., 2025). Rather than viewing digitalization as technological modernization alone, contemporary studies conceptualize it as a multidimensional process involving technological infrastructure, institutional governance, organizational capabilities, innovation management, digital leadership, and human capital development (Verina & Titko, 2019; Castro Benavides et al., 2020; Bui & Nguyen, 2023; Gkrimpizi et al., 2023; Farias-Gaytan et al., 2023; Mukul & Büyüközkan, 2023; Rêgo et al., 2024; Paje & Palaoag, 2024; Dwivedi et al., 2023).

This multidimensional understanding is consistently reflected in studies on digital readiness, digital maturity, and digital competencies. Although these concepts represent different analytical perspectives, they converge on the conclusion that sustainable digital transformation depends on the interaction between technological infrastructure, organizational readiness, institutional governance, and innovation capabilities. Educational institutions with higher levels of digital maturity demonstrate greater adaptability, organizational resilience, and capacity to implement digital innovations (Melnychenko et al., 2021; Ifenthaler & Egloffstein, 2020; Latifah et al., 2022; Rêgo et al., 2024; Stef et al., 2026; Zhao et al., 2025).

A substantial body of research further identifies educators' digital competence as a critical enabling condition for successful digital transformation. The European DigCompEdu framework has become one of the most widely adopted methodological references for assessing educators' digital competence across diverse educational contexts through surveys, self-assessment instruments, comparative analyses, and case studies (Redecker, 2017). Higher levels of educators' digital compe-

tence contribute to instructional quality, educational innovation, and institutional adaptability (Tondeur et al., 2025; Khotimah et al., 2026). Similar conclusions are reflected in Ukraine, emphasizing that systematic development of digital competencies strengthens institutional resilience and supports educational modernization (Bykov et al., 2020; Pakhomova et al., 2023; Ovcharuk, 2023). The implementation of SELFIE for Teachers in Ukraine further illustrates the growing role of evidence-based assessment of educators' digital competencies in educational policy and professional development (Ministry of Education and Science of Ukraine, 2025).

Complementing academic research, international organizations have developed numerous methodological frameworks and composite indices, including those produced by UNESCO, OECD, the International Telecommunication Union, the Network Readiness Index, the World Intellectual Property Organization, the United Nations Development Programme, Digital Planet, and the China National Academy of Educational Sciences. They assess different dimensions of digital development, including infrastructure, connectivity, innovation capacity, digital skills, human capital, educational development, and technology adoption (ITU, 2025; Reynoso & Lanvin, 2025; World Intellectual Property Organization, 2025; United Nations Development Programme, 2025; Digital Planet, 2025; China National Academy of Educational Sciences, 2025). Collectively, these initiatives provide valuable comparative evidence for monitoring digital progress while simultaneously illustrating the multidimensional nature of educational digital transformation.

The rapid diffusion of artificial intelligence and educational technologies has further reinforced this multidimensional perspective. Learning management systems, adaptive learning environments, cloud platforms, artificial intelligence, and learning analytics contribute to personalized learning, institutional efficiency, and evidence-based decision-making only when accompanied by appropriate governance mechanisms, institutional strategies, organizational readiness, and digital competencies (Shard et al., 2024; Bond et al., 2024; Mella-Norambuena et al., 2025; Najmudin et al., 2025; Xia et al., 2024; Rojas & Chiappe, 2024).

Together, these studies reinforce the view that digital transformation represents a systemic process requiring the coordinated development of technological, institutional, and human dimensions rather than isolated technological adoption.

1.2. Educational resilience and conceptual gaps

The growing recognition of digital transformation as a multidimensional phenomenon has increasingly intersected with research on educational resilience, which emphasizes the capacity of education systems to maintain continuity, adapt to disruption, and sustain learning under changing conditions. Contemporary theoretical perspectives, including resilience theory, the capability approach, and socio-technical systems thinking, collectively suggest that educational resilience emerges from the interaction between technological, institutional, organizational, and human factors rather than from technological capacity alone.

From this perspective, digital transformation becomes an enabling condition for institutional adaptability, while resilience depends on the coordinated functioning of infrastructure, governance, organizational capabilities, digital competencies, and innovation processes. This theoretical convergence highlights the need to examine digital transformation and educational resilience as interconnected dimensions of educational system development.

Existing studies predominantly assess individual dimensions of digital transformation such as digital maturity, digital readiness, technology adoption, or digital competencies using different conceptual frameworks, indicator systems, normalization procedures, and weighting approaches (Jian & Mustafa, 2024; Zhao et al., 2021; Stef et al., 2026). Similarly, international composite indices evaluate complementary rather than comprehensive dimensions of digital development, while Ukrainian analytical reports focus on specific aspects such as digital public services, digital literacy, artificial intelligence, educational technologies, and regional digital development (BDO Ukraine, 2025; Ministry of Digital Transformation of Ukraine, 2025a, 2025b, 2025c; IT Ukraine Association, 2025).

This fragmentation reveals a broader conceptual gap: the absence of an integrated framework linking technological, institutional, organizational, and human dimensions into a coherent assessment system. Existing international indices and sector-specific frameworks capture complementary dimensions of digital development but operate at different analytical levels, apply different measurement logics, and rely on heterogeneous indicators. Consequently, they cannot be directly combined into a unified assessment without an explicit methodological architecture that distinguishes contextual evidence from education-specific indicators while preserving conceptual coherence.

1.3. Conceptual foundations of integrated assessment

The proposed methodological framework is designed as an integrated assessment architecture that combines complementary sources of evidence rather than relying on a single measurement approach. It conceptually links statistical evidence, expert judgment, and future integral aggregation into a coherent methodological logic for assessing the digital transformation of the education system. This approach addresses the fragmentation of existing assessment practices by providing a common conceptual structure capable of organizing heterogeneous evidence within a transparent, reproducible, and adaptable assessment logic.

The proposed framework is organized around four complementary determinants that synthesize the recurring dimensions identified in the preceding theoretical analysis:

- Digital Infrastructure, reflecting the technological and connectivity foundations supporting educational systems;
- Digital Competencies, representing the capabilities of educators and learners to participate effectively in digitally transformed educational environments;
- Digital Educational Resources and Technologies, encompassing digital learning environments, educational technologies, and institutional digital practices;

- Digital Potential of Innovative Development, capturing the broader innovation ecosystem that enables long-term digital development and institutional adaptability.

Together, these four determinants establish the conceptual foundation of the proposed integrated assessment framework by linking technological, human, institutional, and innovation dimensions of educational system development. Their complementary relationships provide the basis for structuring the subsequent three-stage assessment architecture while preserving the distinct analytical contribution of each determinant.

To operationalize this conceptual structure, the proposed framework envisages a three-stage assessment architecture. The first stage structures statistical evidence across the four determinants. The second stage proposes a Delphi-based expert weighting procedure for future implementation. The third stage outlines a subsequent integral aggregation procedure designed to support the future calculation of the Integral Digital Transformation Index of Education (IDTIE).

Importantly, this three-stage architecture represents a proposed methodological design rather than a completed empirical implementation. It establishes a transparent, reproducible, and adaptable foundation for the future operationalization of the IDTIE while providing a coherent conceptual basis for integrating diverse statistical evidence within a unified assessment framework for the digital transformation of education in Ukraine. The proposed architecture is designed to remain adaptable for future comparative applications across different educational contexts, territorial levels, and time periods as new evidence becomes available.

The selection of indicators follows a conceptual grouping principle, organizing international indices, national statistical indicators, and institutional evidence by their theoretical relevance to these four determinants rather than merging them into a single operational index. Existing international frameworks are therefore treated as sources of conceptually relevant evidence that contribute to different dimensions of digital transformation while requiring systematic integration within a common

assessment architecture (including the Network Readiness Index, ICT Development Index, Global Innovation Index, Human Development Index, and other complementary assessment systems).

2. RESULTS

The outputs of the study comprise a three-stage assessment architecture, four conceptually grounded determinants, a structured system of potential indicators, and proposed procedures for their normalization, expert weighting, and integral aggregation. Contextual evidence from international, national, and regional sources is subsequently used to demonstrate the availability and analytical relevance of complementary evidence for the future operationalization of the framework. The Delphi assessment and calculation of the Integral Digital Transformation Index of Education (IDTIE) are not undertaken in the present study and are treated as subsequent stages of empirical validation.

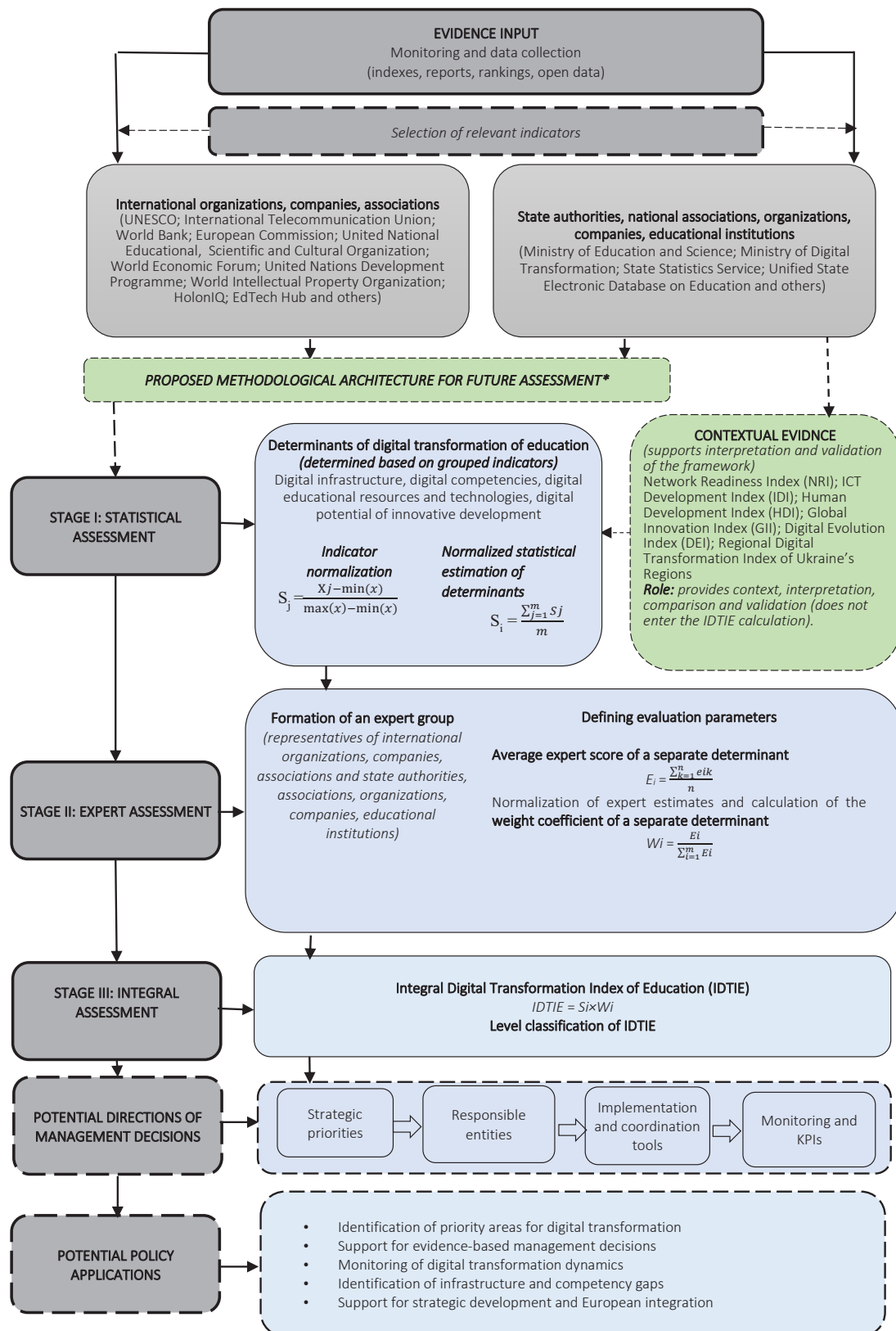
2.1. Proposed architecture of the integrated assessment framework

The methodological framework developed in this study is structured as a three-stage architecture for the future integrated assessment of digital transformation in education in Ukraine (Figure 1).

The framework is primarily designed to assess the digital transformation of the national education system of Ukraine. Its methodological logic can subsequently be adapted to regional, institutional, cross-country, or temporal applications, subject to appropriate modification of the unit of analysis, indicator definitions, and data coverage.

The proposed architecture follows a sequential logic in which statistical and contextual evidence is first structured into a system of candidate indicators, followed by expert-based assessment and weighting, and ultimately by integral aggregation into a composite measure of digital transformation.

Stage 1 involves identifying, classifying, and preparing candidate indicators. The first stage involves identifying and structuring potentially relevant indicators from international and national



Note: The elements and procedures presented in the figure constitute a proposed methodological framework for future empirical implementation and validation.

Figure 1. Conceptual architecture for the future integrated assessment of digital transformation of education in Ukraine

statistics, education-specific datasets, analytical reports, and other relevant sources. The candidate indicators are conceptually organized according to the four proposed determinants of digital transformation in education and classified by analytical level, evidence type, and prospective role in the integrated assessment.

Stage 2 is expert assessment and weighting. The second stage involves a Delphi-based expert assessment of the relevance and relative importance of the selected indicators. This procedure supports the empirical determination of indicator weights and the aggregation of indicators into determinant-level scores. This stage has not been implemented in the present study; therefore, no empirically derived expert weights or consensus estimates are reported.

Stage 3 is integral aggregation and future calculation of IDTIE. The third stage combines normalized indicator values, determinant-level aggregation, and empirically derived expert weights into an integral measure of digital transformation of education. This procedure provides the formal basis for the future calculation of the Integral Digital Transformation Index of Education (IDTIE). The index is prospective in the present study and has not been calculated or empirically validated.

Taken together, the three stages form a coherent methodological architecture for the future integrated assessment of digital transformation in education. The architecture separates the structuring of statistical and contextual evidence from subsequent expert validation, weighting, and integral aggregation. This separation is crucial because the present study develops the conceptual and methodological basis of the assessment rather than performing the Delphi procedure or calculating the IDTIE. Our architecture therefore establishes a transparent basis for subsequent empirical implementation and validation.

2.2. Conceptual determinants of digital transformation in education

Digital transformation of education is a comprehensive process involving the systematic integration of digital technologies, innovative learning models, new forms of interaction among participants in the educational process, and mechanisms for managing educational systems. Assessing it requires considering multiple dimensions that reflect the educational environment's technological readiness, the digital capabilities of educators and learners, the availability and use of digital resources, and the education system's capacity for innovation.

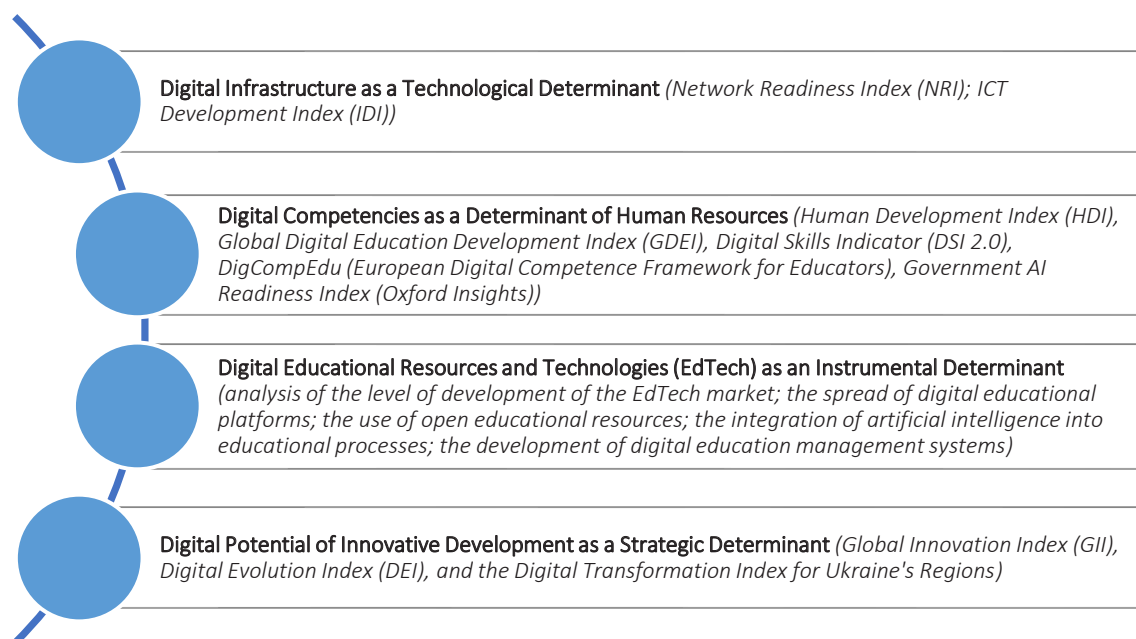


Figure 2. Conceptual determinants and potential assessment dimensions of digital transformation in education in Ukraine

The proposed conceptual framework distinguishes four dimensions of digital transformation in education: digital infrastructure, digital competencies, digital educational resources and technologies, and digital potential of innovative development (Figure 2).

These determinants were developed through a synthesis of international literature, analytical reports, and education-related evidence rather than through empirical factor identification or statistical validation. They provide a conceptual structure for organizing candidate indicators within the future operationalization of the Integral Digital Transformation Index of Education (IDTIE).

Digital infrastructure is a technological determinant of digital transformation in education and ensures effective use of digital technologies in learning, research, and educational management. Its level determines the capacity of education systems to implement distance and blended learning, artificial intelligence, digital platforms, and other educational services, while disparities in infrastructure contribute to the digital divide across regions and educational institutions.

Within the proposed framework, this determinant provides the basis for identifying education-specific infrastructure indicators for future IDTIE operationalization. Indicators such as Internet connectivity of educational institutions and the availability of digital equipment are potential future IDTIE components. Broader national composite indices, including the Network Readiness Index (NRI) and the ICT Development Index (IDI), are contextual evidence on national digital readiness and ICT development rather than direct components of the future IDTIE.

Digital competencies represent the human-capital determinant of digital transformation in education. This determinant encompasses the ability of students, educators, researchers, and education administrators to use digital technologies for learning, communication, content creation, information analysis, research, and professional activities. It also includes opportunities for the continuous development of digital competences through online courses, training, certification, webinars, and digital self-assessment tools.

Within the proposed framework, teachers' digital competence, participation in digital skills development, and other education-related digital skills indicators are potential future IDTIE components. DigCompEdu and SELFIE for Teachers provide education-specific evidence relevant to this dimension. Broader measures, including the Human Development Index (HDI), the Global Digital Education Development Index (GDEI), and the Government AI Readiness Index, are contextual evidence rather than direct measures of education-specific digital competence.

Digital educational resources and technologies represent the resource and technological application determinant of digital transformation in education. This determinant includes digital learning platforms, learning management systems, artificial intelligence applications, open educational resources, and other digital solutions that can enhance the accessibility, quality, personalization, and management of education.

Within the proposed framework, the availability and use of digital learning platforms and digital educational resources are potential future IDTIE components. Broader evidence on the EdTech ecosystem, including market data, investment indicators, and analytical reports, is contextual evidence supporting the interpretation of this dimension rather than a direct component of the future IDTIE.

Digital potential of innovative development is the innovation-oriented determinant of digital transformation in education. It reflects the capacity of education systems to generate, implement, and scale digital innovations through research, innovation ecosystems, digital entrepreneurship, open science, and international cooperation.

Within the proposed framework, indicators of educational innovation, together with relevant research and development and innovation indicators, are potential future IDTIE components. The Global Innovation Index (GII), the Digital Evolution Index (DEI), and regional digital transformation indicators are contextual and diagnostic evidence describing the broader environment within which educational innovation develops.

Together, the four conceptual determinants provide a coherent structure for organizing candidate indicators related to the technological, human, resource, and innovation aspects of digital transformation in education. Their role in the present study is to structure the evidence base and guide the prospective selection of indicators for future IDTIE operationalization. The proposed classification should therefore be understood as a conceptual assessment architecture rather than as an empirically validated taxonomy of determinants.

2.3. Indicator architecture for future IDTIE operationalization

For operationalization of the proposed conceptual architecture, the framework distinguishes potential IDTIE indicators from broader contextual evidence according to their analytical level, evidence type, and intended methodological role. The four conceptual determinants constitute the core dimensions for structuring potential education-specific indicators, whereas international composite indices and regional indicators are treated as contextual and diagnostic evidence. This distinction is intended to prevent the direct aggregation of heterogeneous measures and to maintain the national education system of Ukraine as the primary unit of analysis.

The indicator architecture draws on international and national statistical and analytical sources covering different dimensions of digital transformation in education. The evidence base includes international composite indices, education-related assessment tools, national statistical data, official educational reports, and analytical studies. These sources are used to identify potentially relevant indicators and provide contextual evidence for interpreting the proposed framework. The framework uses evidence available for 2020–2025, depending on source coverage.

The proposed framework is primarily designed to assess the digital transformation of the national education system of Ukraine rather than individual educational institutions or regions. Accordingly, regional indicators are contextual and diagnostic evidence rather than direct components of the national IDTIE. The methodological logic may subsequently be adapted to regional and institutional

applications, provided that the unit of analysis, indicator definitions, and data coverage are appropriately modified.

Given the specific conditions of Ukraine, the proposed framework incorporates wartime-sensitive measurement considerations. Regional statistical evidence is interpreted in light of territorial accessibility, temporary occupation, displacement of educational institutions, disruptions in statistical reporting, and administrative changes caused by the war. Consequently, regional indicators are intended primarily for diagnostic and contextual purposes because their territorial coverage, data availability, and measurement conditions may differ substantially across regions and should not be interpreted as fully comparable territorial measurements. This approach also explains why temporarily occupied territories, including the Autonomous Republic of Crimea and the city of Sevastopol, are not represented by comparable current administrative indicators within the regional evidence used in this study.

Table 1 illustrates the proposed indicator architecture rather than the finalized composition of the future IDTIE. The indicators are grouped according to the four conceptual determinants and differentiated by analytical level, evidence type, and methodological role. Indicators identified as potential future IDTIE components require further empirical operationalization and validation, whereas international composite indices and regional indicators are contextual or diagnostic evidence and are not automatically included in the future integral index.

Based on the proposed indicator architecture, the following specifies the methodological procedures for normalization, determinant-level aggregation, expert weighting, and subsequent integral aggregation.

The first stage involves the preparation of indicators for future integrated assessment. Indicators identified through the synthesis of international literature, statistical sources, and education-specific evidence are grouped according to the four proposed determinants of digital transformation in education. For future empirical implementation, the framework proposes Min-Max normalization,

Table 1. Proposed indicator architecture for future IDTIE operationalization

Determinant	Proposed indicator	Analytical level	Evidence type	Illustrative data source	Role in the proposed IDTIE framework
Digital infrastructure	Internet connectivity of educational institutions	National education system	Statistical	Ministry of Education and Science of Ukraine	Potential future IDTIE component
	Availability of digital equipment	National education system	Statistical	State Statistics Service of Ukraine	Potential future IDTIE component
	Network Readiness Index (NRI)	National (country level)	Composite index	Portulans Institute	Contextual evidence supporting the framework
	ICT Development Index (IDI)	National (country level)	Composite index	ITU	Contextual evidence supporting the framework
Digital competencies	Teachers' digital competence	Individual (teacher level)	Survey-based and self-assessment evidence	DigCompEdu, SELFIE for Teachers	Potential future IDTIE component
	Participation in digital skills development	National education system	Statistical	Ministry of Education and Science of Ukraine	Potential future IDTIE component
	Population digital skills	National (country level)	Statistical	Digital Skills Indicator (DSI 2.0); Ministry of Digital Transformation of Ukraine	Contextual evidence supporting the framework
	Human Development Index (HDI)	National (country level)	Composite index	UNDP	Contextual evidence supporting the framework
	Global Digital Education Development Index (GDEI)	National (country level)	Composite index	China National Academy of Educational Sciences	Contextual evidence supporting the framework
	Government AI Readiness Index	National (country level)	Composite index	Oxford Insights	Contextual evidence supporting the framework
Digital educational resources and technologies	Availability of digital learning platforms	National education system	Statistical	Ministry of Education and Science of Ukraine	Potential future IDTIE component
	Use of digital educational resources	National education system	Statistical	Official educational reports	Potential future IDTIE component
	EdTech ecosystem indicators	National (country level)	Analytical report	BDO Ukraine, IT Ukraine Association	Contextual evidence supporting the framework
Digital potential of innovative development	Educational innovation indicators	National education system	Statistical	Ministry of Education and Science of Ukraine	Potential future IDTIE component
	Research and development and innovation indicators	National (country level)	Statistical	State Statistics Service of Ukraine	Potential future IDTIE component
	Global Innovation Index (GII)	National (country level)	Composite index	WIPO	Contextual evidence supporting the framework
	Digital Evolution Index (DEI)	National (country level)	Composite index	Digital Planet	Contextual evidence supporting the framework
	Regional digital transformation indicators	Regional	Statistical	Ministry of Digital Transformation of Ukraine	Diagnostic and contextual evidence

which transforms indicators measured in different units into a common 0-1 scale (Equation 1).

$$S_j = \frac{x_j - \min(x)}{\max(x) - \min(x)}, \quad (1)$$

where S_j – normalized value of the j -th statistical indicator (component); x_j – actual value of the j -th indicator (component) for Ukraine; $x_{\min}$ – minimum value of the corresponding indicator (component); $x_{\max}$ – maximum value of the corresponding indicator (component).

For indicators with an inverse relationship to digital transformation, we apply the corresponding reverse normalization procedure. We specify the reference range during future empirical implementation based on the analytical purpose and data structure.

Following normalization, indicators are aggregated into determinant-level statistical estimates (Equation 2):

$$S_i = \frac{\sum_{j=1}^m S_j}{m}, \quad (2)$$

where S_i – proposed i -th determinant-level statistical estimate; S_j – normalized value of the j -th statistical indicator (component); m – number of indicators (components).

These normalized statistical estimates provide the quantitative basis for the subsequent expert and integral assessment stages. In the proposed framework, determinant-level statistical estimates constitute the intermediate output of the first stage and are designed to support future expert weighting and integral aggregation rather than represent completed empirical assessment results.

The second stage of the proposed framework incorporates expert judgments about the relative strategic importance of the four determinants. A Delphi-based procedure is proposed for future empirical operationalization and therefore has not been implemented in the present study.

Within the proposed procedure, experts assess the relative importance of each determinant using a 10-point scale. A future expert panel may include

representatives of public authorities, international organizations, educational institutions, professional associations, and other relevant stakeholders. Average expert scores and corresponding weighting coefficients are subsequently derived from these assessments.

Future empirical research may calculate the average expert assessment as follows (Equation 3):

$$E_i = \frac{\sum_{k=1}^n e_{ik}}{n}, \quad (3)$$

where E_i – average expert assessment of the i -th determinant; E_{ik} – assessment assigned by the k -th expert; n – number of experts.

The corresponding weighting coefficient is subsequently derived as follows (Equation 4):

$$W_i = \frac{E_i}{\sum_{i=1}^m E_i}, \text{ with } \sum_{i=1}^m W_i = 1, \quad (4)$$

where W_i – weighted coefficient of the i -th determinant; E_i – average expert assessment; m – number of determinants.

The resulting weighting coefficients characterize the relative importance of the four determinants rather than their current level of development. Because the Delphi procedure constitutes a proposed stage of future empirical implementation, these coefficients are presented as elements of the methodological architecture rather than as empirically derived values.

The third stage of the proposed framework concerns the integral aggregation of determinant-level statistical estimates and expert-derived weighting coefficients. If the proposed expert assessment is subsequently implemented, the resulting determinant-level estimates and weights could be combined into the following integral measure (Equation 5):

$$IDTIE = \sum S_i \cdot W_i, \quad (5)$$

where $IDTIE$ – Integral Digital Transformation Index of Education; S_i – normalized statistical estimate of the corresponding determinant; W_i – weighting coefficient intended to be derived from the proposed expert assessment procedure.

Under the proposed aggregation procedure, the proposed integral index is designed to range from 0 to 1, with higher values indicating a higher level of digital maturity of the national education system. Since the integral aggregation stage represents future empirical operationalization, the proposed index should be interpreted as a methodological outcome of the conceptual framework rather than as an empirically calculated value.

2.4. Contextual evidence supporting the proposed framework

The international indices, national statistical sources, analytical reports, surveys, and regional evidence considered in this study provide contextual and illustrative evidence supporting the relevance of the four conceptual determinants incorporated into the proposed framework. The evidence base covers information available for 2020–2025, subject to differences in source coverage and methodology, and is interpreted at different analytical levels, including the national education system, country, teacher, institutional, and regional levels. This differentiation is essential because the proposed framework does not treat indicators measured at different levels as interchangeable. Accordingly, country-level composite indices are used primarily as contextual evidence, education-specific measures as potential future IDTIE components, and regional indicators as diagnostic evidence of territorial conditions.

Digital infrastructure represents the technological determinant of digital transformation in education and provides the foundation for the effective use of digital technologies in learning, research, and educational management. Its development affects the capacity of education systems to implement distance and blended learning, artificial intelligence, digital platforms, and other digital educational services. At the same time, differences in infrastructure availability may contribute to digital inequalities between regions and educational institutions.

Within the proposed framework, education-specific indicators such as Internet connectivity of educational institutions and the availability of digital equipment are potential future IDTIE components. Broader national indices are used only as contextual evidence of the technological environ-

ment in which the digital transformation of education takes place.

The Network Readiness Index (NRI) was considered as contextual evidence of Ukraine's national digital readiness rather than as a direct measure of education-specific digital infrastructure. In 2025, Ukraine ranked 46th among 127 economies with an overall score of 54.30/100 (Reynoso & Lanvin, 2025). Among indicators relevant to the proposed infrastructure determinant, Internet access in schools scored 98.99 (37th place) under the Technology Access pillar, indicating broad connectivity in educational institutions. Other NRI indicators related to connectivity and ICT skills were complementary evidence for identifying potential infrastructure indicators. The overall NRI score and country ranking were therefore not incorporated directly into the proposed IDTIE but were used to characterize the broader digital conditions in which the digital transformation of education takes place.

The ICT Development Index (IDI) was used as contextual evidence of Ukraine's broader digital development. The index captures dimensions related to ICT access, use, and benefits and therefore provides complementary evidence for the infrastructure and digital-capacity determinants of the proposed framework. In 2025, Ukraine ranked 52nd among 164 economies with an IDI score of 85.8 (ITU, 2025). The overall IDI score was not treated as a direct component of the IDTIE because it aggregates dimensions extending beyond the education sector. Instead, relevant underlying indicators were considered as potential sources for constructing education-specific measures.

The available evidence is consistent with the conceptual interpretation of digital infrastructure as a necessary enabling condition for digital education. International evidence also indicates that connectivity, access to digital technologies, and the availability of appropriate digital infrastructure are closely associated with the capacity of education systems to sustain digital forms of learning and educational management (UNESCO, 2023). Our evidence is therefore used to support the conceptual relevance of the infrastructure determinant rather than to establish its empirical contribution to an already calculated integral index.

Digital competencies represent the human-capital dimension of educational digital transformation. This determinant encompasses the ability of students, educators, researchers, and education administrators to use digital technologies for learning, communication, content creation, information analysis, and professional activities. It also includes opportunities for continuous professional development through online courses, training, certification, webinars, and digital self-assessment instruments.

Within the proposed framework, teachers' digital competence and education-related digital skills development are potential future IDTIE components, while population-level digital skills are treated as contextual evidence. Education-specific frameworks and assessment instruments provide more direct evidence for these measures, whereas broader human-development and digital-readiness indices serve primarily contextual purposes.

The Human Development Index (HDI) was considered as contextual evidence of the broader human-development conditions relevant to digital competence formation. In 2025, Ukraine recorded an HDI of 0.779 and ranked 87th among 193 countries (United Nations Development Programme, 2025). Since the HDI combines education, health, and income dimensions, its aggregate value was not treated as a direct measure of digital competencies and was therefore not included as a direct component of the future IDTIE. Its role is limited to characterizing the broader human-capital environment in which digital competencies develop.

More specific evidence is provided by the Digital Skills Indicator (DSI 2.0), which supports monitoring of population digital skills within the European Digital Decade framework and is linked to the target of at least 80% of adults possessing basic digital skills by 2030 (European Commission, Joint Research Centre, 2025). In Ukraine, digital skills are increasingly assessed through the Diia.Education platform using Digital Grades based on the DigComp 2.1 framework, with related activities supported by cooperation between the Ministry of Digital Transformation of Ukraine and EU4DigitalUA (Ministry of Digital Transformation of Ukraine, 2025a, 2025b, 2025c; EU4Digital, n.d.).

The DigCompEdu framework and its implementation through the SELFIE for Teachers initiative in Ukraine in 2025–2026 provide education-specific evidence, focusing on educators' digital competence and professional development needs (Redecker, 2017; Ministry of Education and Science of Ukraine, 2025). Such evidence is more directly relevant to the future operationalization of the digital competencies determinant than broader country-level composite indices and may inform the selection of potential future IDTIE indicators.

The Global Digital Education Development Index (GDEI) provides contextual evidence on national progress in educational digitalization, including teacher development and digital learning environments (China National Academy of Educational Sciences, 2025). Ukraine is not currently represented in the index due to its country-selection methodology and limitations in statistical reporting under wartime conditions. Nevertheless, the GDEI provides an international reference for identifying and developing potential education-specific indicators within the proposed framework.

The Government AI Readiness Index provides contextual evidence of institutional capacity relevant to digital transformation. In 2025, Ukraine ranked 40th among 195 countries, with particularly strong performance in the digitalization of public services (Ministry of Digital Transformation of Ukraine, 2025a). However, the index does not directly measure the digital competencies of teachers or students and is therefore not proposed as a direct component of the future IDTIE.

National evidence provides more specific information on population digital capacity. In 2025, 96% of Ukrainians were reported to possess digital skills, while 58% had at least basic digital skills; the share lacking basic digital skills decreased from 15% in 2019 to 4% in 2025 (Ministry of Digital Transformation of Ukraine, 2025b). These data provide illustrative evidence of changes in population digital capacity and may inform the selection of potential future indicators, but they do not constitute an empirical assessment of the digital competencies determinant within the future IDTIE.

Taken together, the evidence indicates the availability of multiple sources for describing digital competence at different analytical levels. However, the differences in definitions, populations, measurement instruments, and units of analysis require these sources to be treated separately during future operationalization. This supports the distinction established in Table 1 between education-specific candidate indicators and broader contextual evidence.

Digital educational resources and technologies constitute an important determinant of digital transformation, encompassing digital learning platforms, online resources, artificial intelligence, and other technologies that support teaching, learning, and educational management.

Within the proposed framework, the availability of digital learning platforms and the use of digital educational resources are considered potential future IDTIE components, whereas evidence on the development of the broader EdTech ecosystem and related investment is treated as contextual evidence.

The development of the Ukrainian EdTech ecosystem provides contextual evidence of the growing technological capacity supporting digital education. According to the IT Ukraine Association (2025), Ukrainian EdTech companies attracted more than USD 401 million in investments during 2020–2023, including approximately USD 84 million in 2023, accounting for about 2.3% of global EdTech investment (HolonIQ, 2023). The Ukrainian EdTech ecosystem includes technology companies, educational institutions, and specialized service providers. Market projections for the educational metaverse also indicate potential technological expansion, although such indicators reflect market development rather than the digital transformation of the education system itself.

Evidence concerning the actual use of digital educational resources provides a more education-specific perspective on digital transformation. National survey evidence covering 3,223 respondents indicates the use of both Ukrainian and foreign digital resources for online self-education, with substantial differences across user groups. Among the adult population, Diia.Education was reported by 52.2% of respondents, while ChatGPT

was used by 67.0%; among teenagers, the corresponding shares were 43.8% and 71.2%, respectively. Other Ukrainian resources, including Prometheus and EdEra, were used by 16.6% and 8.3% of adults, respectively, while Duolingo was reported by 35.5% of adults and 49.4% of teenagers (Ministry of Digital Transformation of Ukraine, 2025b). The evidence also reveals substantial differences among respondents with hearing and visual impairments, indicating that the use of digital educational resources is closely related to accessibility and user characteristics.

These findings provide illustrative evidence of the diffusion and actual use of digital educational resources and technologies in Ukraine. However, the reported shares reflect resource-specific use among particular respondent groups rather than the overall digital transformation of the education system. They should therefore be interpreted as contextual and education-specific evidence that can inform the selection of potential indicators for the future IDTIE rather than as a direct component of the national integral assessment. The variation across user groups further demonstrates the need to account for accessibility, population characteristics, and measurement scope when selecting and operationalizing potential indicators.

Institution-level evidence provides an additional education-specific perspective on the implementation of digital technologies. According to the BDO Ukraine survey, many higher and professional pre-higher education institutions report partial rather than complete readiness for digital transformation, while approximately one-third characterize themselves as fully prepared for digital change (BDO Ukraine, 2025). Institutions use learning management systems, cloud services, videoconferencing platforms, electronic document management systems, and selected ERP solutions. Approximately 83% of surveyed institutions reported using free artificial intelligence applications, including ChatGPT, Midjourney, Claude, and Google AI, for educational and administrative purposes. At the same time, insufficient funding, outdated infrastructure, limited digital competencies, resistance to organizational change, and the absence of comprehensive digital strategies remain important barriers to digital transformation (BDO Ukraine, 2025).

The available evidence further suggests that the development of digital education depends not only on the availability of high-quality EdTech solutions but also on their accessibility, dissemination, institutional adoption, and adaptation to the needs of different user groups. These considerations are conceptually relevant to digital inclusion and support the interpretation of digital educational resources and technologies as a distinct determinant within the proposed framework for the future assessment of digital transformation in education in Ukraine.

The evidence therefore supports the inclusion of digital educational resources and technologies as a distinct conceptual determinant. At the same time, market size, investment volumes, platform use, and resource availability measure different aspects of the digital educational environment and should not be aggregated without additional operational definitions and empirical testing. In the future IDTIE, education-specific indicators would require clearly defined units of analysis, observation periods, data sources, and transformation rules.

Digital potential of innovative development represents the fourth strategic determinant of educational digital transformation. It reflects the capacity of an education system to generate, implement, and scale digital innovations through research and development, innovation ecosystems, digital entrepreneurship, open science, technology transfer, and international cooperation.

Within the proposed framework, educational innovation indicators together with relevant R&D and innovation measures are considered potential future IDTIE components. Broader innovation and digital-maturity indices are treated as contextual evidence describing the environment within which digital innovation in education can develop.

The Global Innovation Index (GII) was considered as contextual evidence of the national innovation environment relevant to digital potential for innovative development. In 2025, Ukraine ranked 66th among 139 economies (WIPO, 2025). Because the GII covers broad institutional, infrastructural, human-capital, market, business, and innovation-output dimensions, its aggregate score was not in-

terpreted as a direct measure of educational innovation and was therefore not incorporated into the future IDTIE. Its role is limited to characterizing the broader innovation environment surrounding the education system.

The Digital Evolution Index (DEI) provides complementary contextual evidence of national digital maturity and transformation dynamics. In 2025, Ukraine ranked 61st in the Digital Evolution: State subindex with a score of 52.70 and 38th in the Digital Evolution: Momentum subindex with a score of 65.40, while its overall position was 83rd among 125 economies (Digital Planet, 2025). The relatively stronger Momentum position compared with State provides illustrative evidence of dynamic digital development alongside remaining structural constraints. These results are used to characterize the broader digital and innovation environment and do not constitute empirical validation of the digital potential for innovative development determinant or a direct component of the future IDTIE.

Regional evidence provides a complementary diagnostic perspective on territorial conditions surrounding digital transformation. The Digital Transformation Index of Ukraine's Regions, developed by the Ministry of Digital Transformation of Ukraine with the support of the Swiss-Ukrainian EGAP Programme, covers digital skills, digital public services, digital infrastructure, digitalization of local communities, and the digital economy (Ministry of Digital Transformation of Ukraine, 2025c). Within the proposed framework, these indicators are used to illustrate regional differences and contextual conditions rather than as direct components of the national IDTIE.

Interpretation of regional evidence requires particular methodological caution under wartime conditions. The available data are based on information submitted by regional state or military administrations and are affected by territorial accessibility, temporary occupation, displacement, disruptions in statistical reporting, and administrative and institutional changes caused by the war. Consequently, regional indicators are treated primarily as diagnostic and contextual evidence rather than as fully comparable territorial measurements. The Autonomous Republic of Crimea

and the city of Sevastopol are not represented in the comparative regional evidence because comparable current administrative data are unavailable under temporary occupation. For Donetsk, Luhansk, Zaporizhzhia, Kherson, and other war-affected regions, the reported values should not be interpreted as measurements covering the entire de jure administrative territory or all educational institutions historically associated with the respective regions (Table 2). Therefore, regional differences should be interpreted in light of unequal security, accessibility, territorial coverage, and reporting conditions rather than as directly comparable measurements of regional digital transformation.

A comparative analysis of the regional evidence presented in Table 2 indicates substantial territorial variation. Among the regions included in the available evidence, Lviv, Dnipropetrovsk, Ternopil, Rivne, and Poltava reported relatively high overall scores, whereas Donetsk, Zaporizhzhia, and Luhansk recorded lower values. These differences should not, however, be interpreted as straightforward rankings of the digital transformation of education because the regional index measures broader digital development and is affected by differences in territorial conditions, administrative capacity, infrastructure, and wartime disruption.

Table 2. Regional digital transformation evidence relevant to the proposed assessment framework in Ukraine, 2025

Region*	Sub-indices					Overall digital transformation index
	Digital skills	Digitization of public services	Digital infrastructure	Digitization of local communities	Digital economy	
Vinnitsia	63.29	54.75	47.35	30.1	11.98	42
Volyn	72.35	61.67	61.95	32.9	8.92	48
Zhytomyr	60.07	57.66	53.9	18.5	8.5	42
Zakarpattia	53.15	62.7	64.31	35.1	13.98	47
Ivano-Frankivsk	66.35	56.85	55.71	30.2	11.96	45
Kyiv	39.92	63.3	81.8	38.2	15.77	50
Kirovohrad	76.57	54.48	77.25	13.6	12.44	50
Lviv	89.84	72.55	65.86	52.8	12.26	57
Poltava	96.06	60.1	61.11	29.1	7.74	51
Rivne	98.55	58.57	64.86	29.7	11.94	52
Ternopil	100.0	65.47	63.08	35.4	18.41	55
Khmelnitskyi	78.89	48.2	57.95	29.7	11.94	44
Cherkasy	31.4	54.86	57.04	30.1	16.07	40
Chernivtsi	32.53	56.15	49.83	28.0	11.96	38
War-affected regions of Ukraine						
Dnipropetrovsk	85.22	73.43	72.47	36.1	9.79	57
Donetsk	40.04	50.06	27.24	14.6	11.93	31
Zaporizhzhia	53.78	44.73	28.84	11.9	12.03	31
Luhansk	44.06	40.6	36.06	11.4	11.93	30
Mykolaiv	76.38	47.1	55.56	32.6	11.98	43
Odesa	59.03	57.3	47.93	30.3	4.47	41
Sumy	89.96	50.05	48.19	32.9	11.95	44
Kharkiv	69.12	64.29	59.6	38.5	16.35	49
Kherson	72.05	48.29	49.46	21.3	40.03	44
Chernihiv	70.01	61.37	58.9	28.1	11.94	47

Note: *The table reports regional values available from the source and excludes territories identified in the official List of territories where hostilities are (were) taking place or that are temporarily occupied by the Russian Federation, approved by Order No. 376 of the Ministry of Community and Territorial Development of Ukraine dated February 28, 2025, and registered with the Ministry of Justice of Ukraine on March 11, 2025, under No. 380/43786. For regions affected by hostilities or partial temporary occupation, the reported values should not be interpreted as measurements covering the entire de jure administrative territory. The measurement results are based on data submitted by officials of regional state (military) administrations through the electronic reporting system of the "Diia. Digital Community" web portal. Because territorial accessibility, institutional coverage, reporting conditions, displacement, and administrative circumstances vary across regions, the reported regional values are used in this study solely as contextual and diagnostic evidence and should not be interpreted as fully comparable territorial measurements or as direct components of the national IDTIE.

To illustrate the regional conditions relevant to the proposed framework, Figure 3 presents selected sub-indices from the Digital Transformation Index of Ukraine's Regions that are particularly relevant to digital transformation in education. These include digital skills, digital public services, digital infrastructure, and the digitalization of local communities, which provide diagnostic evidence of territorial differences in the broader digital environment affecting education (Ministry of Digital Transformation of Ukraine, 2025c) (Figure 3).

Regional indicators are used primarily to identify territorial disparities and contextual conditions relevant to digital transformation in education, while the primary unit of analysis for the future national IDTIE remains the national education system of Ukraine. Regional data may subsequently support a separate regional adaptation of the framework, subject to appropriate modification of the unit of analysis, territorial coverage, data availability, and indicator definitions.

Taken together, the regional evidence complements the broader contextual evidence by illustrating how digital infrastructure, digital competencies, public digital services, and regional digital capacity vary across Ukraine under wartime conditions. These observations support the interpretation of regional indicators as diagnostic and contextual evidence within the proposed framework rather than as direct components or empirical validation of the future national IDTIE.

At the broader level, the international indices, national statistics, surveys, analytical reports, and regional evidence demonstrate the availability of heterogeneous information relevant to the four conceptually distinguished dimensions of digital transformation in education: digital infrastructure, digital competencies, digital educational resources and technologies, and digital potential for innovative development. The evidence also illustrates substantial differences in analytical level, population coverage, measurement approach, and territorial conditions. Accordingly, broader composite indices such as the NRI, IDI, HDI, GII, DEI, GDEI, and Government AI Readiness Index are treated as contextual evidence, whereas education-specific measures may constitute potential future IDTIE components, and regional indicators provide diagnostic evidence of territorial conditions.

The evidence therefore supports the conceptual relevance of the proposed four-dimensional architecture and demonstrates the availability of potentially suitable data sources for its future operationalization. However, it does not establish statistical relationships among the dimensions, empirically validate their structure, or constitute a completed assessment of the Integral Digital Transformation Index of Education. This evidence base consequently provides a foundation for subsequent empirical procedures, including the final selection and operational definition of indicators, normalization, expert assessment and weighting, sensitivity analysis, and integral aggregation.

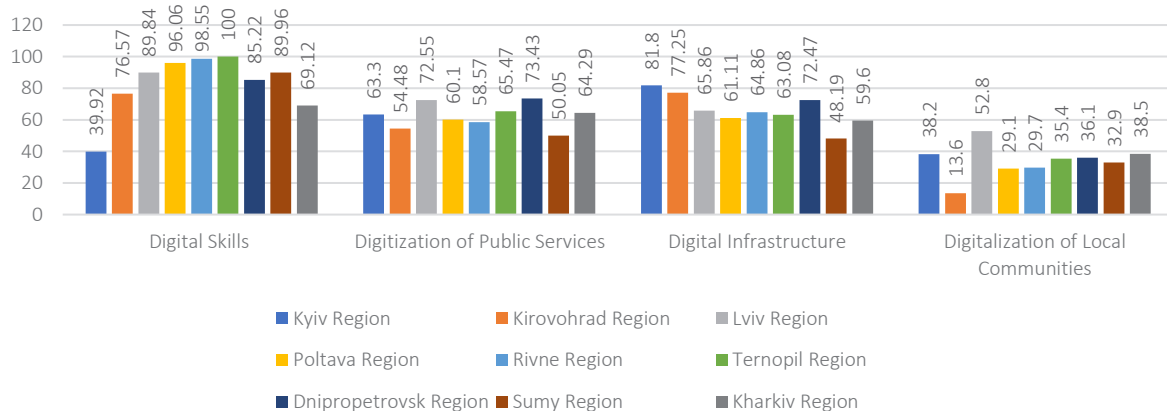


Figure 3. Selected regional digital transformation conditions relevant to the digitalization of education in Ukraine, scores

3. DISCUSSION

The main contribution of the study is the development of a theoretically grounded and wartime-sensitive methodological architecture for the future integrated assessment of digital transformation in education in Ukraine. The proposed framework responds to the conceptual fragmentation identified in the theoretical literature by organizing heterogeneous evidence within a common assessment logic. It brings together four complementary dimensions (digital infrastructure, digital competencies, digital educational resources and technologies, and digital potential of innovative development) and links them to a three-stage methodological architecture comprising indicator identification and classification, future expert assessment and weighting, and subsequent integral aggregation. The contribution therefore lies not in calculating a new index, but in establishing a conceptual and methodological basis for its future development. In this respect, the framework preserves the distinct analytical role of statistical evidence, contextual evidence, and future expert judgments while providing a structured pathway toward the future calculation of the Integral Digital Transformation Index of Education (IDTIE).

The proposed architecture is consistent with the multidimensional understanding of digital transformation developed in previous research. Existing studies have examined digital maturity, digital readiness, digital competencies, technology adoption, organizational capabilities, and innovation from different conceptual perspectives (Castro Benavides et al., 2020; Ifenthaler & Egloffstein, 2020; Mukul & Büyüközkan, 2023; Rêgo et al., 2024; Stef et al., 2026). Other research emphasizes the interaction of technological, human, organizational, institutional, and innovation-related factors in digital transformation (Castro Benavides et al., 2020; Dwivedi et al., 2023; Paje & Palaoag, 2024). Our framework systematizes these recurring dimensions into four conceptual determinants and connects them with an explicit methodological sequence for future assessment. This should not be interpreted as an empirically validated taxonomy; rather, the four determinants represent a theoretically substantiated structure for organizing candidate indicators identified through the synthesis of

literature, international assessment frameworks, national evidence, and education-specific sources. The emphasis on digital competencies is consistent with research highlighting educators' digital competence as an important condition for educational quality, institutional adaptability, and effective technology integration (Redecker, 2017; Tondeur et al., 2025; Khotimah et al., 2026). Similarly, the inclusion of digital educational resources and technologies reflects the growing importance of learning platforms, artificial intelligence, learning analytics, and other digital solutions, while recognizing that their educational value depends on accessibility, institutional readiness, governance, and appropriate digital competencies (Bond et al., 2024; Mella-Norambuena et al., 2025; Xia et al., 2024). The fourth determinant, digital potential of innovative development, complements these perspectives by emphasizing the capacity of education systems to generate, implement, and scale digital innovations through research and development, innovation ecosystems, entrepreneurship, technology transfer, and related institutional mechanisms (Stojanov & Daniel, 2024; Zhao et al., 2021). Thus, the framework offers a way to organize conceptually related dimensions within a common assessment logic without assuming that broader international indices or sector-specific indicators are directly interchangeable.

A further methodological implication concerns the distinction between education-specific indicators and broader contextual evidence. International composite indices such as the Network Readiness Index, ICT Development Index, Human Development Index, Global Innovation Index, Digital Evolution Index, Global Digital Education Development Index, and Government AI Readiness Index provide valuable information about the technological, human-capital, innovation, institutional, and digital environments in which education systems operate. However, these indices differ in scope, analytical level, indicator composition, and measurement purpose. Their aggregate scores therefore cannot be automatically interpreted as measures of the digital transformation of education or directly incorporated into a national education-specific index. The same applies to regional digital transformation indicators, population-level digital skills, institutional surveys, and EdTech market evidence, which repre-

sent different units of analysis and evidence types. The proposed architecture addresses this issue by distinguishing potential future IDTIE components from contextual and diagnostic evidence. This distinction is important for maintaining conceptual coherence and avoiding the direct aggregation of heterogeneous measures simply because they are associated with digital development. In this respect, the framework complements rather than replaces existing international indices, national monitoring systems, and education-specific assessment instruments.

The Ukrainian context adds an important war-time-sensitive dimension to the proposed assessment logic. Previous research has shown that major disruptions, including the COVID-19 pandemic and the full-scale war in Ukraine, accelerated the adoption of digital technologies while simultaneously exposing inequalities in access, infrastructure, competencies, and institutional readiness (Williamson et al., 2020; Vorotnykova et al., 2023; Sytnykova et al., 2024). The evidence considered in this study further demonstrates that digital transformation conditions vary substantially across Ukrainian regions. At the same time, regional data cannot be interpreted independently of territorial accessibility, temporary occupation, displacement of educational institutions and populations, disruptions in statistical reporting, and administrative and institutional changes caused by the war. These factors affect both data availability and comparability. Accordingly, regional indicators are positioned in the proposed framework primarily as diagnostic and contextual evidence rather than as direct components of the national IDTIE. This methodological distinction is particularly important for regions affected by active hostilities or occupation, where reported indicators may not represent the entire *de jure* territory or all educational institutions historically associated with a region. The absence of comparable current administra-

tive indicators for the Autonomous Republic of Crimea and the city of Sevastopol further illustrates the limitations of applying uniform territorial measurement procedures under conditions of prolonged occupation. The wartime context therefore should not be treated merely as an external background factor but as a methodological condition affecting the interpretation, coverage, and comparability of digital transformation evidence.

The proposed framework also defines a clear direction for future empirical operationalization. Our study does not report empirically derived determinant scores, expert assessments, weighting coefficients, or calculated IDTIE values. The Delphi procedure presented in the methodological architecture remains prospective, as does the subsequent integral aggregation. Future research should therefore determine the final set of education-specific indicators, define their operational measures and reference ranges, apply appropriate normalization procedures, conduct the proposed expert assessment and weighting, and calculate the integral index. Subsequent empirical research should also examine the sensitivity and robustness of the resulting index, assess the stability of expert-derived weights, compare alternative aggregation procedures, and evaluate temporal comparability. When adapting the framework for regional or institutional assessment, one should explicitly modify the unit of analysis, indicator definitions, territorial coverage, and data requirements. These procedures are necessary to determine whether the proposed conceptual architecture can provide a reliable and valid basis for integrated measurement. Our study consequently establishes the methodological foundation for such empirical work while maintaining a clear distinction between the conceptual contribution developed here and the future stages of index construction, empirical testing, and validation.

CONCLUSION

The study aimed to develop and substantiate a methodological framework for the integrated assessment of digital transformation in education in Ukraine by systematizing its key determinants and establishing a conceptual basis for the operationalization of the Integral Digital Transformation Index of Education.

The results demonstrate that integrated assessment of digital transformation in education requires a structured approach capable of distinguishing education-specific indicators from broader contextual and diagnostic evidence. The proposed framework identifies four interrelated determinants (digital infrastructure, digital competencies, digital educational resources and technologies, and digital potential of innovative development) and organizes them within a coherent three-stage methodological architecture. This architecture provides a basis for structuring potential indicators, incorporating expert judgment, and subsequently aggregating evidence without treating heterogeneous measures as directly interchangeable. The analysis also shows that international indices, national statistics, education-specific assessment instruments, surveys, and regional indicators provide complementary evidence, but differ in analytical level, measurement logic, territorial coverage, and methodological purpose.

A key conclusion is that the national education system of Ukraine should remain the primary unit of analysis in the proposed integrated assessment, while regional indicators should primarily serve contextual and diagnostic purposes. This distinction is particularly important under wartime conditions, when occupation, displacement, disrupted statistical reporting, territorial accessibility, and administrative changes affect the coverage and comparability of regional evidence. The proposed architecture therefore provides a transparent and wartime-sensitive basis for organizing available evidence while preserving the complementary role of existing international indices and national monitoring systems.

The proposed framework constitutes a methodological foundation rather than a completed empirical index: the final selection and operational definition of education-specific indicators, Delphi-based expert weighting, normalization, integral aggregation, and empirical validation remain subsequent research tasks. Future empirical application should assess the reliability, sensitivity, robustness, and temporal comparability of the resulting Integral Digital Transformation Index of Education and, where appropriate, adapt the framework to regional, institutional, or comparative applications through explicit modification of the unit of analysis, indicator definitions, and data requirements.

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