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RESEARCH ARTICLE

Developing Indicators for School Digital Renewal in the Age of AI

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Abstract The school digital renewal process (SDRP) has evolved from adoption at the infrastructure level to deep pedagogical transformation centered on personalized, competence-based learning. Traditional indicators, such as device availability or connectivity, lose relevance at advanced SDRP stages. This paper proposes a novel, evidence-based approach to constructing indicators that capture shifts in learning content and organization through an automated analysis of schools' digital footprints using AI tools, such as publicly available digital resources. Drawing on the Bloom's revised taxonomy and empirical data from international schools, we demonstrate the feasibility of tracking second-order changes without relying on teacher surveys. The framework supports the comparative monitoring of digital transformation aligned with the demands of the age of AI. The paper introduces a groundbreaking innovation: the use of AI tools for gathering and analyzing indicators from publicly available digital resources in schools. This approach offers a scalable and cost-efficient method of tracking and evaluating SDRP at the later stages of development.

Keywords school digital renewal process (SDRP), personalized competence-based learning, Bloom's revised taxonomy, AI in education, digital transformation indicators, ChatGPT, educational scenarios

1 Introduction

In 1960, S. I. Shvartsburd, a teacher at Moscow's secondary school No. 444, led the world's first group of programmers and operators of second-generation electronic computing machines. Over the subsequent five decades, breakthroughs in digital technologies (DTs), including the emergence of personal computers and the global shift from analog across all major domains of information and communication, have repeatedly swept through schools, accelerating DT integration into education. The recent proliferation of intelligent tools powered by AI is further intensifying this transformation.

The emphasis is placed not merely on the introduction of new DTs but on the transformative changes they bring to educational systems, a process referred to as the school digital renewal process (SDRP). SDRP encompasses changes in the educational environment, teaching and learning practices, school management, teacher professional development, and the school's relationship with other stakeholders in the local community. Its ultimate promise lies in its potential to create more personalized learning and enable teachers to achieve a long-standing goal of supporting each student's personal development. This means that every student can attain the full range of subject-specific, cross-curriculum, meta-subject, and personal competencies needed to thrive in the modern world.

Digital renewal is a long-term process in which schools move through a sequence of stages shaped by waves of technological progress and qualitative shifts in educational practice. In its early stages, SDRP was measured by indicators, such as the quality of internet connectivity, the availability of digital devices, and the access to educational online services. As it advances, digital renewal impacts the entire learning environment, including both the visible and the invisible: people, technology, physical classroom and layout, and objects in the classroom (books, notes, websites, software, school buildings, and cultural environment) (Sawyer, 2014). As schools become increasingly better equipped with DTs, SDRP starts to influence all aspects of the educational process, from curricula and content to pedagogical methods and school's entire learning environment.

In its latter stages, SDRP involves more than the updating of digital infrastructure and teaching methods; it requires a fundamental rethinking of traditional organizational structures and management

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processes. The transformation occurs both horizontally (impacting more schools, teachers, and students) and vertically (introducing more effective teaching methods supported by evolving DTs). These changes are driven by new learning expectations and a shift from classroom-centered teaching to personalized, competency-based learning (PCBL). At this stage, the focus extends beyond technology to broader educational goals, including fostering new forms of school–community partnerships (parents, local authorities, and businesses), rethinking educational aims and content, and updating teaching tools, methods, and learning outcomes.

While such profound changes cannot happen without DTs, technology-based metrics alone are no longer sufficient for assessing progress at advanced stages of SDRP. This paper outlines a framework for constructing evidence-based indicators that capture deeper transformations of the latter SDRP stages, using a conceptual model that differentiates early-stage and advanced-stage innovations in education. It also explores future trajectories for educational systems that leverage technology to enhance learning outcomes. The core innovation of this paper is its employment of AI tools to collect and analyze indicators based on public digital resources from schools in order to assess changes in SDRP at the later stages of its development. It is a scalable and low-cost method for monitoring the digital transformation of education.

2 Stages of School Digital Renewal Process

A review and systematization of approximately one thousand publications on the integration of DTs into schools over recent decades has revealed more than two dozen distinct descriptions of SDRP. These can be grouped into two main categories: qualitative descriptions (futuristic visions, stage-based frameworks, and normative guidelines) and conceptual models (comprehensive role models, formalized practice-oriented frameworks, and standardized theoretical models).

Qualitative descriptions helped shape the future visions and informed planning for the anticipated changes. As SDRP evolved, more structured models emerged, incorporated indicators, defined stages, and expected outcomes. With the increasing adoption of DTs, normative descriptions were developed, specifying requirements, recommendations, and standards for elements, such as school equipment, teacher's digital literacy, and resource provisioning. Most models were created within the context of DT integration projects, with the aim of building assessment and management tools for school improvement.

Implementation across regions, countries, and territories has been uneven, with each school progressing toward digital renewal at its own pace and under its own local conditions. Nevertheless, researchers have identified common developmental stages initiated by advances in DTs and their penetration into education (Twining, 2008; Uvarov et al., 2019). The notion of stages has become well established and is now employed, among others, by the developers of the *Global digital education development index* (China National Academy of Educational Sciences (CNAES), 2025). While the numbers and names of stages vary, they consistently describe similar transformative processes, which can be summarized into four stages (see Figure 1).

The overarching goal of SDRP at the aforementioned four stages in Figure 1 is to enhance the effectiveness of educational organizations and improve the quality of both teacher's and student's development. Each stage reflects school's technical infrastructure, teacher's digital literacy, and the accumulated institutional experience in applying DTs to everyday educational practice. Understanding the current state of digital transformation allows school leaders and the local authorities to more accurately assess progress and establish realistic goals.

At the first stage, the primary focus is on equipped schools with DTs and developing basic digital literacy between teachers and students. At this stage, pioneering administrators and colleagues innovate by employing DTs to enhance educational practices. Preliminary experience is also gained in applying DTs to school management tasks.

At the second stage, digital educational environment (DEE) and digital literacy become routine elements of school life. The emphasis shifts to applying DTs in subject teaching, creating new digital tools and materials, and introducing innovative pedagogical practices supported by DTs.

At the third stage, schools engage in systematic efforts to modernize teaching methods and organizational structures, leveraging an increasingly sophisticated DEE from the following six aspects: (1) reliable access for all participants to the Internet, digital tools, and learning resources at both school and home; (2) integration of DTs to enable diverse forms of interaction and collaborative learning replacing traditional paper-based methods; (3) expansion of interdisciplinary projects supported by DTs; (4) extension of learning beyond the classroom through blended and online modalities; (5) use of DTs for authentic formative and summative assessment; and (6) increased experience in individualized learning for students.

At the fourth stage, new technological solutions drive a qualitative transformation of school

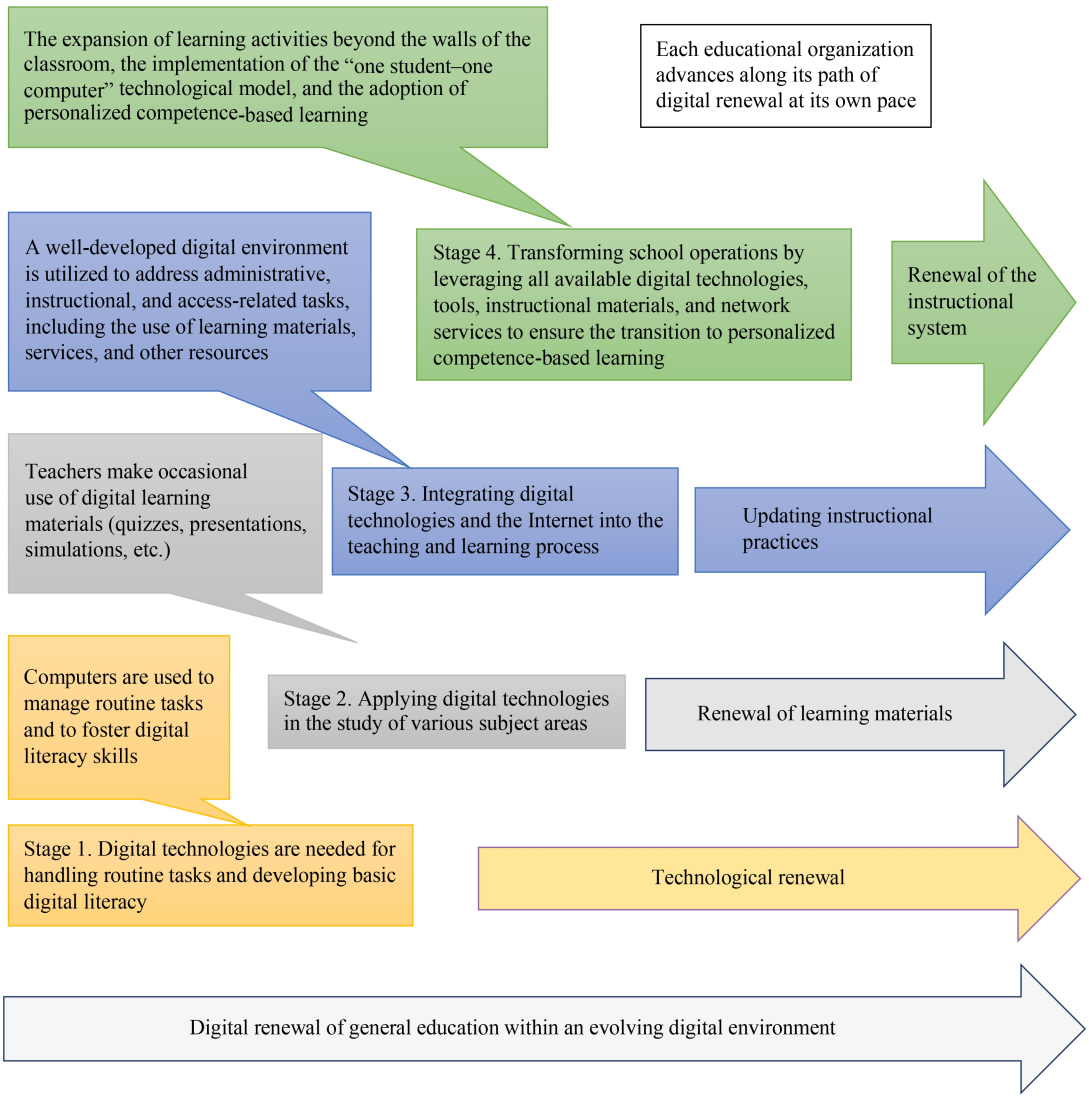

Figure 1 Four stages of digital renewal within a developing digital environment (Uvarov, 2020).

operations. This stage represents a shift from simply introducing DTs to fundamentally rethinking teaching and learning in a rapidly evolving DTs. Central to this transformation is the move from traditional classroom-based teaching to PCBL (Uvarov, 2022). The aim is to ensure that every student achieves all required personal outcomes, meta-subject outcomes, cross-curriculum, and subject-specific outcomes defined by educational standards.

PCBL tailors learning to the capabilities, needs, strengths, and pace of each student. Learners progress only after demonstrating the mastery of current instructional materials, supported by formative assessments that quickly identify learning gaps and guide targeted interventions. Personalized learning platforms (PLPs), which support through combining organizational and methodological elements of the educational process, help manage the learning process of each student, and deliver learning materials, enabling anytime–anywhere learning that blends independent work, teacher–student interaction, and group collaboration.

Evidence of the effectiveness of individualized approaches has long existed (Bloom, 1984). Proven methodological development for the implementation of this model of teaching and learning in secondary schools appeared more than ten years ago (Stoll & Giddings, 2015). With recent digital advances, they have become feasible at scale. Summit learning supported by Chan Zuckerberg Initiatives (Summit Learning Education Technology Spotlight, 2025) in the late 2010s provided an early large-scale demonstration of successful PCBL implementation. The model has been replicated in more than three hundred schools and school districts in the United States and has been positively evaluated by teachers (Summit Learning Teacher Feedback Study Results, 2021). In this model, students actively participate in setting goals and deciding how to engage with content. Nowadays, according to the

OECD's *Digital education outlook 2023: Towards an effective digital education ecosystem*, about 45% of the developed countries are piloting and scaling personalized learning in secondary education (OECD, 2023). Under these conditions, the management of this process and the conduct of comparative international studies require robust, evidence-based indicators for assessing how general education schools implement PCBL in the course of developing SDRP.

A central challenge at the fourth stage of digital renewal in education is the reorientation of educational priorities. According to the *Digital education council global AI student survey 2024* (Digital Education Council, 2024), the vast majority of students already incorporate AI into their studies. The rapid proliferation of digital tools is reshaping traditional conceptions of creativity, redefining learning objectives, and emphasizing the importance of higher-order thinking skills, collaboration, lifelong learning, and adaptability. There is a need to cultivate a balanced integration of declarative, procedural, conceptual, and epistemic dimensions of education. Traditional disciplinary structures require renewal through greater interdisciplinarity, accommodating advances in modern technology and engineering while deepening engagement with social sciences and entrepreneurship. AI-enabled personalization offers a promising avenue for aligning educational aims with the demands of contemporary society (Betts et al., 2021; Bowen & Watson, 2024).

Nowadays, schools face the dual challenge of redefining educational aims while ensuring that every student achieves them. In the AI era, this requires moving beyond uniform classroom teaching to personalized, competency-based models where the mastery level is progress metric. Such approaches reduce achievement gaps, accelerate advanced learners, and prepare all students for further study or early professional engagement. Despite progress, global monitoring of 62 countries with long-standing SDRP shows that incidences of achieving stage 4 remain rare (CNAES, 2025). About 13% of leading nations are still at stage 1, 68% at stage 2, and only 19% have reached stage 3. These observations are in good agreement with the findings presented in Dvoretskaya and Uvarov (2025). The transition to stage 4 requires a fundamentally different type of innovation compared to those that schools have dealt with in the previous stages of digital renewal.

3 First-Order and Second-Order Changes

Throughout history, educators have sought to improve schooling through contemporary technologies. Some, like the printing press, became integral to educational practice. Others, such as the laterna magica, radio, or television, were initially heralded as revolutionary but ultimately failed to produce systemic shift. Similarly, many instructional media (slide projectors, tape recorders, and teaching machines) left only a limited mark on schooling. By contrast, DTs of the past fifty years have profoundly reshaped information practices and stimulated entirely new models of learning, such as PCBL. AI-powered intelligent tools promise to further move the school renewal, but the transition to stage 4 of the SDRP poses significant challenges, since the required changes are fundamental.

Almost forty years ago, Larry Cuban posed the question, "Why do schools and classrooms resist repeated and significant efforts to change?" (Cuban, 1988). He suggested that school leaders distinguish between two types of change:

- First-order (incremental efficiency)—change within the system. Focuses on improving the efficiency or effectiveness within the current system's structure. It fixes a problem without altering the underlying goals, values, or power dynamics.
- Second-order (fundamental transformation)—change of the system. Focuses on changing the structures, goals, roles, and values of the system itself. It is a paradigm shift that requires a new way of thinking.

First-order change improves efficiency without disturbing basic organizational characteristics, while second-order change creates transformation and seeks to alter fundamental ways. Failing to recognize the difference is a key reason why many change initiatives fail when apply a first-order solution to a problem that requires a second-order shift (Fullan, 1993). First-order change involves modest adjustments (new teaching methods, materials, and tools) that enhance efficiency or engagement without challenging school's core structures or values. These changes are typically low-cost, short-term, and initiated at the classroom or school level. They may be evaluated through student performance data, engagement metrics, or qualitative feedback.

Second-order change is far more profound, altering the purposes, structures, governance, and culture of education. They demand a rethinking of fundamental aspects, such as equity, assessment, curriculum design, and the roles of teachers and students. These transformations usually require substantial investment, long-term planning, and coordinated leadership, with evaluation focusing on strategic indicators, like institutional agility, stakeholder satisfaction, and sustainability.

Peggy A. Ertmer applied the change framework to the specific challenges of educational technology integration. His article provided a framework for practitioners by categorizing the barriers to technology integration into two distinct groups (Ertmer, 1999), based on the first- and second-order change model.

First-order barriers (featured as external or extrinsic) are institutional and external barriers that can be overcome by resources and management (a first-order change solution). They are relatively easy to identify and fix, provided sufficient funding and administrative will. For example, lack of access to hardware or software, institutional support and so on.

Second-order barriers (featured as internal or intrinsic) are fundamental barriers rooted in teacher's beliefs and requiring a second-order change solution. They are far more resistant to change, even when the first-order barriers are removed.

While first-order changes operate at a micro level and can be piloted quickly, second-order changes occur at a macro level, often across entire systems, and may take years to realize. Both types are important, but only second-order changes, such as the systemic shift to PCBL, can address the structural challenges of preparing students for the complexities of the AI-driven world.

The transition to PCBL to prepare younger generation for life in an AI era is a significant second-order change. It is associated with solving not just technological and methodological problems but also with cultural transformations in the school's operations and the everyday lives of local communities, which fully prepared each student in accordance with high-level education standards. This is the central reason why, despite the forward-looking statements made by policymakers and the frequently encountered passive or active resistance of the bureaucratic educational systems, the transition from the third to the fourth stage of SDRP may proceed via three possible scenarios.

4 Three Theoretical Scenarios for the Development of School Digital Renewal

Publicly funded general education, which emerged in the early seventeenth century, has continuously evolved alongside broader societal transformations. The starting points can be considered the establishment of Europe's first public school in 1613 in Frascati, Italy, or the adoption of the law on public financing of primary education in 1633 in Scotland. These changes became especially pronounced during the twentieth century. Yet throughout this period, traditional classroom–lesson model has remained the dominant organizational framework in education. On this foundation, bureaucratic educational systems developed to fulfill the mandate of universal compulsory education. Despite recurring criticism, these systems have, albeit imperfectly, continued to meet the objectives of general education. When considering future trajectories for educational development, three primary theoretical scenarios emerge: inertial scenario, transformational scenario, and divergent scenario.

The inertial scenario assumes that resource constraints and institutional inertia limit the scope of transformative change, reinforcing tendencies toward the centralization and preservation of the established practices. In this context, necessary reforms occur only incrementally and are typically driven by localized, school-level initiatives as first-order changes that do not challenge the core educational system.

The transformational scenario, by contrast, envisions the deliberate design, piloting, and scaling of a fundamentally new educational model, PCBL. This second-order change aims to enhance the quality of general education while cultivating key competencies required for life, work, and lifelong learning in the age of AI.

It is reasonable to expect that under the inertial scenario, systemic tensions will intensify. In response, stakeholders from the emerging educational sector, embedded within the digital economy, may enter the market to compensate for the shortcomings of traditional schools, offering learner competencies not addressed by the formal curriculum. This could lead to the third scenario, the divergent or "school–dissolution" scenario (Uvarov, 2020). All three scenarios involve the active use of DTs, but the purposes they serve differ significantly (see Table 1).

Table 1 Three theoretical scenarios for the development of schools

Theoretical scenario	Scenario feature	Role of digital technology (DT)
Inertial *"In order to stay in the same place, one must run as fast as one can."*	The classroom–lesson model remains dominant, sustained by centralized governance and formalized procedures. Innovation is tolerated only if it does not disrupt the existing system	DTs support top–down decision-making, centralize control, and standardize instructional content and methods, reinforcing uniformity of practices
Transformational *"In order to move forward, one must run even faster."*	Schools evolve into cultural clusters and hubs for lifelong learning, implementing personalized, competence-based learning to ensure that every student achieves all required learning outcomes	DTs enable personalized, outcome-driven instruction, foster 21st-century skills, maintain high engagement, and support collaboration between schools and communities
Divergent *"Let a hundred flowers bloom."*	The effectiveness of traditional school declines as learners turn to online and community-based alternatives. The formal school system becomes increasingly diffuse	DTs expand access to learning beyond schools, enabling homeschooling, network-based education, and the growth of supplementary education services

Each scenario represents an idealized, pure form of change: a theoretical construct illustrating an extreme case. In reality, the interplay of diverse social, political, and economic factors will produce hybrid configurations that combine elements of all three.

Inertial scenario. This scenario is grounded in the preservation of the classroom–lesson model as the primary organizational framework. DTs are used mainly to replace or enhance traditional teaching tools, with pedagogical innovations permitted only to the extent that they do not require systemic shift. The result is innovation without transformation. School operations become increasingly formalized, with DTs employed to support top–down decision-making, centralized control, and standardized instructional content and methods. Six characteristic features include (1) standardization of curricula, teaching methods, and organizational formats; (2) reinforcement of centralized control mechanisms; (3) decision-making concentrated at regional or national levels; (4) education viewed primarily as a pathway to formal certification; (5) low professional status and remuneration for teachers; and (6) limited public trust in educational institutions.

The inertial model reflects a context in which, due to insufficient funding, weak community engagement, inadequate pedagogical research, or stakeholder disinterest, the traditional school model and prevailing teaching practices persist. Policy directives and public critique fail to produce meaningful shifts. In this setting, innovative uses of DT are confined to incremental, first-order changes, with priorities focused on building regional or national digital information systems for automating data collection, monitoring teacher performance, and supporting conventional instruction. Teachers often resist externally imposed reforms, exert minimal influence on educational outcomes, and leave systemic challenges unaddressed (Kapuza & Kolygina, 2020). These conditions foster the growth of alternative educational pathways accelerated by the erosion of traditional social structures, such as family and local communities.

Transformational scenario. In this scenario, schools evolve into cultural and learning centers for local and professional communities, becoming spaces for personal growth and lifelong learning. This scenario aims to achieve the main goals of general education, which are promoting holistic personal growth, developing independent learning, and ensuring that each student gains meta-subject, cross-curriculum, and subject-specific knowledge according to the established standards. Six key features include (1) the expansion of the traditional classroom–lesson model into PCBL; (2) schools functioning as learning organizations that reliably develop 21st-century skills in all graduates; (3) the reduction of formalism through a hi-tech and hi-touch approach that maintains high levels of engagement among students and teachers; (4) broad community involvement in the continuous improvement of schools; (5) creation of a rich educational environment integrating physical, social, and digital dimensions to support transformation; and (6) widespread adoption of DT-supported practices that enable every student to achieve required learning outcomes.

At this stage, SDRP transcends the mere implementation of digital tools or the development of digital literacy. It simultaneously addresses two complex challenges: (1) modernizing learning objectives and content with an emphasis on 21st-century skills; (2) shifting from "education for all" to "education for each", ensuring that every student's potential is realized and all required outcomes are achieved.

Transformational change drives the widespread adoption of active learning practices supported by PLPs, digital resources, and intelligent tools that enable personalization. Creative and research-oriented activities become integral to daily school life. This transition requires well-prepared subject specialists, mentors, and school leaders who are capable of working in new ways and who enjoy the respect of their communities.

In a world characterized by liquid modernity and the fragmentation of family and local communities (Bauman, 2000; Carnoy, 2000), transformed schools play a vital role in supporting robust social and emotional development. Achieving this demands second-order changes and the implementation of pilot study to design and test new school models. Successful implementation depends on the coordinated action across all levels of educational governance and sustained support for educators. Rapid advances in AI are becoming a key driver of this transformation.

Divergent scenario. In the divergent scenario, the declining effectiveness of traditional schools is offset by a growing ecosystem of alternative educational services. As a result, the formal school system becomes increasingly fragmented. Five key characteristics include (1) students seeking educational opportunities outside formal school system; (2) the expansion of online learning services and local or virtual learning communities; (3) widespread adoption of DT-supported homeschooling; (4) growth in importance of supplementary education providers offering digital programs; and (5) significant use of AI to broaden access to learning beyond the formal school system.

The divergent scenario assumes that societal efforts to transform public education are failing. Parental dissatisfaction with school performance fuels demand for alternatives, accelerating the growth of online education markets (Byun et al., 2018). Parents become more involved in school-related decisions, yet concerns remain that the proliferation of intelligent educational services may revive pre-mass-schooling patterns of inequality (Uvarov, 2022). Moreover, these alternatives often fail to fulfill critical, though often overlooked, functions of public schools, such as ensuring equitable access, providing childcare, and mitigating the digital divide.

It is unlikely that a purely divergent scenario will be fully realized. Instead, it will likely coexist with inertial and transformational trajectories, leading to a fragmented educational landscape in which multiple pathways evolve simultaneously (see Figure 2).

As the digital economy advances, the inertial scenario will, in most contexts, eventually give way to the transformational scenario marked by a systemic shift from the classroom–lesson model to PCBL (a second-order change). If this transition is delayed or fails, societal pressures may gradually replace the traditional school system with alternative structures under the divergent scenario in Figure 2. However, because the divergent path is inherently unstable, its expansion may catalyze transformation, prompting societies to adopt the transformational model to preserve educational and social cohesion.

Initiatives, such as the *Global digital education development index* (GDEI) of CNAES can generate data to assess the pace, scale, and direction of these shifts, including whether changes occur gradually or abruptly, possibly through an intermediate divergent stage (CNAES, 2025). Such instruments are required to include indicators capable of capturing the dynamics of curricular renewal and the reorganization of the educational process, particularly the transition toward PCBL.

5 Towards an Evidence-Based Assessment of School Transformation

This paper proposes a framework for constructing indicators to monitor schools' progress during the advanced stage of the SDRP, which is the stage where second-order changes predominate. At this juncture, transformation is evidenced by a systemic shift from traditional instruction to PCBL, accompanied by the renewal of learning objectives and a stronger emphasis on higher-order thinking skills.

The spread of innovative teaching and learning practices is a critical dimension of SDRP. Table 2 compares the indicator sets employed by three major international frameworks, *OECD digital education outlook 2023*: *Towards an effective digital education ecosystem* (OECD, 2023), GDEI (CNAES, 2025), and *UNESCO Institute for Information Technologies in Education (IITE) Information and Communication Technology (ICT) in education toolkit* (UNESCO Asia and Pacific Regional Bureau for Education & Southeast Asian Minsters of Education Organization Regional Centre for Educational Innovation and Technology 2003; UNESCO IITE et al., 2002; UNESCO IITE & Shanghai Open University, 2023), against three evaluation criteria: (1) capacities to capture the transition to PCBL; (2) grounding in empirical evidence rather than perception-based data; and (3) abilities to reflect updates in learning goals and the development of high-level competencies.

The analysis (see Table 2) reveals that while all three frameworks provide valuable system-level insights, none fully satisfies all three criteria simultaneously. In particular, there remains a dearth in scalable, objective, and automatable indicators capable of capturing actual changes in curriculum content and pedagogical practice without relying on teacher surveys or observational protocols.

To address this, we focus on two core dimensions of educational transformation: (1) educational content renewal; and (2) learning process renewal.

5.1 | Indicators for Educational Content Renewal

Educational content is traditionally understood as the curated body of knowledge, skills, values, and

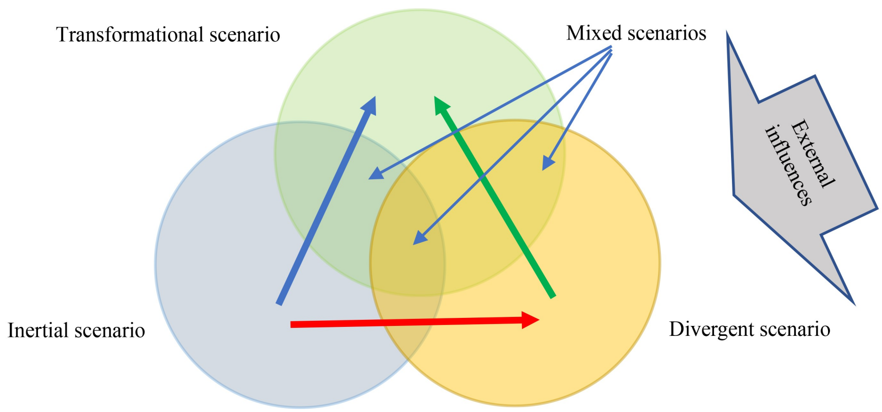

Figure 2 Transitions between scenarios of digital school renewal (Uvarov, 2020).

competencies that students are expected to master. It is formally articulated in curricula, standards, and instructional materials. Contemporary pedagogical design, however, demands that content be expressed through operationalized learning outcomes. They are clear, measurable statements of what students should know and be able to do and paired with aligned assessment procedures.

Therefore, updating educational content entails more than revising syllabi; it involves redefining expected outcomes and embedding formative and summative assessments directly into learning activities. In the context of SDRP, such renewal is driven by two complementary forces: the integration of digitally relevant topics (coding, digital literacy, and data ethics) and the operationalization of long-advocated but previously implicit competencies (critical thinking, collaboration, and self-regulation).

To assess the extent and depth of this renewal, we suggest considering two complementary indicators: scale of renewal and depth of renewal. First, the scale of renewal is measured by the number of new or revised learning outcomes introduced in a school's official curriculum relative to a reference (baseline) curriculum. This includes updates across compulsory subjects, electives, interdisciplinary modules, and project-based courses. Second, the depth of renewal is assessed by mapping each learning outcome to Bloom's revised taxonomy (Anderson & Krathwohl, 2001). Learning outcomes targeting higher-order thinking processes, particularly "evaluate" and "create", signal a deeper transformation aligned with the demands of the AI era.

Table 2 Indicator comparison matrix: *OECD digital education outlook 2023*: *Towards an effective digital education ecosystem*, GDEI, and *Global practices evaluation & assessment toolkit*

Framework	Scope and data source	Transition to PCBL	Evidentiality	Learning goals
OECD digital education outlook 2023: *Towards an effective digital education ecosystem* (OECD, 2023)	System-level administrative data, national surveys, PISA-linked outcomes, and labor-market indicators	**Limited**. Strong on system access and attainment, but offering only indirect, aggregating proxies for personalization; no direct measurement of classroom-level pedagogical change	**Partial**. Robust at enrollment, spending, but lacking process-level evidence on individualized instruction or formative practices	**Partial**. Attainment and PISA domains providing coarse-grained insight into changing goals but omitting fine-grained indicators for creativity, self-regulation, or problem-solving
GDEI (CNAES, 2025)	Multi-dimensional index, including infrastructure, policy, digital content, digital literacy, governance, and teaching reform. Combination of national statistics and qualitative policy reviews	**Indirect**. Measuring enablers of adaptive platforms and digital resources, indirect assess actual implementation of personalized or competence-based practices in classrooms	**Mixed**. Using documented policies and national data, yet lacking validated, transparent, classroom-level indicators; public reporting often omitting methodological details	**Emerging**. Tracking integration of digital literacy and curricular updates as intent signals, but not systematically measuring student development of higher-order thinking skills
Global practices evaluation & assessment toolkit (UNESCO Asia and Pacific Regional Bureau for Education & Southeast Asian Minsters of Education Organization Regional Centre for Educational Innovation and Technology, 2003; UNESCO IITE et al., 2002; UNESCO IITE & Shanghai Open University, 2023)	Framework recommending mixed-method indicators across input, use, output, and outcome levels, including classroom observation, teacher surveys, performance tasks, and policy analyses	**Most aligned**. Explicitly supporting indicators for pedagogical use of ICT, student-centered tasks, and competence-based practices, when fully implemented at national level	**Strong**. Prioritizing direct observation and performance-based assessment over self-reports; discouraging reliance on input-only metrics	**Well-aligned**. Including curriculum and assessment indicators for 21st-century skills, enabling tracking of goal revision and competency development, contingent on consistent implementation

Notes. OECD: Organization for Economic Co-operation and Development, GDEI: *Global digital education development index*, PISA: Programme for International Student Assessment, PCBL: personalized, competence-based learning, ICT: information and communication technology.

Table 3 Cognitive process dimension: categories and processes (revised from Anderson and Krathwohl's (2001) research)

Bloom's taxonomy dimension	Remember (1)	Understand (2)	Apply (3)	Analyze (4)	Evaluate (5)	Create (6)
Key words of each dimension	Recognizing (1.1) and recalling (1.2)	Interpreting (2.1), exemplifying (2.2), classifying (2.3), summarizing (2.4), inferring (2.5), comparing (2.6), and explaining (2.7)	Executing (3.1), implementing (3.2), and applying (3.3)	Differentiating (4.1), organizing (4.2), and attributing (4.3)	Checking (5.1) and critiquing (5.2)	Generating (6.1), planning (6.2), and producing (6.3)

For example, a curriculum that emphasizes procedural knowledge and application ("remember", "understand", and "apply" in Table 3) reflects limited renewal, whereas one that routinely requires students to design solutions, critique arguments, or generate original media demonstrates substantive alignment with PCBL principles. The combined metric, which integrates scale and depth, provides a nuanced picture of curricular evolution. Crucially, as digital renewal advances, depth becomes more significant than scale.

The growing availability of AI-powered text analysis tools makes it feasible to automate the extraction and classification of learning outcomes from publicly accessible school documents (curricula, syllabi, and project briefs), enabling the large-scale, low-burden monitoring of content renewal.

5.2 | Indicators for Learning Process Renewal

The learning process can be conceptualized as a sequence of learning cycle, as a guidance for students to optimize their learning, which includes six indicators: (1) clarification of objectives; (2) engagement with materials and tasks; (3) formative assessment; (4) adjustment of learning strategies; (5) summative assessment; (6) reflective review.

In the traditional classroom models, a sequence of learning cycle is synchronized throughout the class, which implies the same learning rate for everyone. However, this does not correspond with reality and often results in distorted cycles when critical stages, such as formative feedback and reflection, are missed or addressed superficially. It reduces instructional effectiveness and increases achievement gaps.

In contrast, PCBL relies on individualized learning cycle, where in progression is contingent on demonstrated mastery. Each student follows a personalized trajectory, with the cycle duration and support calibrated to their needs. This shift represents a fundamental transformation of the educational process.

To monitor this transformation, a holistic system of indicators reflects changes virtually in all key operational aspects of the school. These changes can be grouped into three interconnected processes: (1) renewal of the educational process, including the updating of learning content and the organization of learning process (sustainable organizational, pedagogical, and methodological support); (2) transformation of the school's operating mode which organizes and implements the educational process and its renewal, including expansion of the controllable component of the chronotope of the learning process and enhancement of the personalization of staff professional development; (3) development of the educational environment supporting the dynamics of the two preceding processes, including humanization of the social components, refinement of the physical components, and expansion of the accessibility of the virtual components of the educational environment, and modification of the profiles and volume of the educational organization' s digital footprints, which enables the tracking of ongoing changes.

The rapidly accelerating process of digital transformation in education is making the development of a holistic system of indicators increasingly urgent. The success of this endeavor depends substantially on the extent to which it is realistic to rely on AI-powered tools.

5.3 | A Pilot Study on Automating Content-Renewal Assessment

To test the feasibility of automating content-renewal assessment, we conducted a pilot study using ChatGPT to extract and classify learning objectives from the digital resources of schools using Bloom's revised taxonomy as the analytical framework (Anderson & Krathwohl, 2001). The subject-area "Technology", which typically encompasses multiple interdisciplinary courses, was selected for data collection due to its dynamic evolution and strong alignment with educators increasingly formulating learning objectives that fall in with higher-order thinking skills. Learning objectives were coded using the two-dimensional taxonomy framework (Anderson & Krathwohl, 2001). Categories and processes of the cognitive process dimension in Bloom's taxonomy, as well as the types and sub-types of the knowledge dimension, are presented in Tables 3 and 4.

Data were collected from five general education schools in Europe and Latin America (ORT1–ORT5), all supported by World ORT. A subject specialist from World ORT, familiar with

Table 4 Knowledge dimension: types and subtypes (revised from Anderson and Krathwohl (2001))

Knowledge dimension	Factual knowledge	Conceptual knowledge	Procedural knowledge	Metacognitive knowledge
Key content of each dimension	Knowledge of terminology and knowledge of specific details and elements	Knowledge of classifications and categories; knowledge of principles and generalizations; and knowledge of theories, models, and structures	Knowledge of subject-specific skills and algorithms; knowledge of subject-specific techniques and methods; and knowledge of criteria for appropriate use	Strategic knowledge; knowledge about cognitive tasks, including appropriate contextual and conditional knowledge; and self-knowledge

these institutions, validated the AI-generated findings against his professional understanding of the instructional practices and curricula. The experiment unfolded in four stages:

In the stage 1, identification of official digital resources (school websites, partner platforms, and social media) using targeted search queries in English and local languages utilizing domain-specific and site-specific search operators; in the stage 2, systematic retrieval of documents containing explicit learning objectives (curricula, standards, project reports, and lesson plans); in the stage 3, extraction and classification of learning goals using the revised taxonomy, with each statement coded along two dimensions: the knowledge dimension (see Table 4) and the cognitive process dimension (see Table 3). The identified learning goals were assigned to corresponding types and sub-types of knowledge dimension, as well as corresponding categories and processes of cognitive process dimension in Bloom's taxonomy. This classification was guided by the established methodological frameworks and the illustrative examples provided in the revised taxonomy; in the stage 4, synthesis of results into structured, source-cited analytical reports for each school (see Table 5) and analysis of the materials in the analytical reports.

The expert confirmed that the AI-generated analysis closely aligned with his professional understanding of the schools' instructional priorities. This suggests that AI tools can reliably automate the initial stages of indicator construction, bypassing surveys and subjective input while enabling cross-school comparisons.

The data obtained showed that learning goals are unevenly distributed among knowledge dimension's types. Goals related to the formation of metacognitive knowledge were absent in all schools, and goals related to factual knowledge were stated in only one elementary school. To check whether this phenomenon is typical only for ORT schools or not, it was decided to supplement the experimental sample with two comprehensive schools from Finland, one of which is primary (Fin-1 and Fin-2). The selected Finland schools are well known in the educational community for their

Table 5 An excerpt from the analytical report for one of the schools

Subject (module)	Learning objective	Knowledge dimension	Bloom's taxonomy dimension
Technology (design and technology)	Follow safety requirements and act responsibly when using tools, machines, and digital devices during design tasks	Factual knowledge: knowledge of specific details and elements (safety rules)	Apply: executing
	Compare similar solutions and characterize the materials and technological processes used; identify which steps of the design process were taken	Conceptual knowledge: knowledge of classifications and categories; knowledge of principles and generalizations	Understand: comparing
	Plan and implement a solution in a chosen design domain, reflecting on the process and its impact on environment and health	Procedural knowledge: knowledge of subject-specific techniques and methods	Apply: implementing
Robotics	Assemble and test a simple mechatronic and robotic device following a given design	Procedural knowledge: knowledge of subject-specific skills and algorithms; knowledge of subject-specific techniques and methods	Apply: executing
	Debug a simple robot program by identifying the step that causes the unexpected behavior and correcting it	Procedural knowledge: knowledge of subject-specific techniques and methods; knowledge of criteria for appropriate use	Analyze: attributing
Digital technologies (mapped to information technologies)	Use core digital technologies to create and share information for schoolwork (documents, presentations, and media) according to task requirements	Procedural knowledge: knowledge of subject-specific techniques and methods	Apply: executing
	Use digital technologies safely, effectively, and responsibly in the design and learning process (data protection and respectful communication)	Conceptual knowledge: knowledge of principles and generalizations; knowledge of criteria for appropriate use	Apply: executing
Information technologies	Apply a given algorithm in a visual programming environment to solve a simple problem	Procedural knowledge: knowledge of subject-specific skills and algorithms	Apply: executing
	Develop a simple program that implements a provided algorithm to control behavior in a chosen environment	Procedural knowledge: knowledge of subject-specific techniques and methods	Apply: implementing
Digital media production	Produce a 30–60 second video to communicate a message, meeting rubric criteria for clarity, composition, sound, and ethics	Procedural knowledge: knowledge of subject-specific techniques and methods	Create: producing
	Critique a peer's short video using the class rubric and suggest one concrete improvement	Conceptual knowledge: knowledge of principles and generalizations	Evaluate: critiquing

leadership in digital education. Both Fin-1 and ORT-1 are elementary schools.

The collected data provides a rich material for analysis. In order to compare the levels of learning goals that different schools set for themselves, for each of the schools, for each process from the cognitive process dimension, the number of goals for each types from the knowledge dimension was calculated. The resulting graphs are shown in Figure 3.

The collected data showed that metacognition knowledge was missing from educational programs in Finnish schools and this phenomenon is not just typical for ORT schools. That is why in Figure 3, there is no distribution of learning goals according to cognitive processes in terms of metacognitive knowledge. Data from Finnish and ORT schools are quite similar overall. An interesting difference emerged in the Bloom's taxonomy dimension: in Finnish schools, these objectives align with recognizing in "remember" dimension, whereas in ORT schools, they correspond to executing in "apply" dimension. This can be attributed to the well-known emphasis of ORT curricula on developing practical skills. The data also reveal that learning objectives across ORT schools are not homogeneous, although they are relatively consistent in their focus on procedural knowledge.

The pilot study demonstrates that automated, evidence-based monitoring of SDRP is not only feasible but scalable. Today, researchers should integrate this approach into long-term projects, which will link the update of educational goals, content, and organizational forms with specific steps and stages in digital transformation.

6 Conclusions

The digital transformation of schools in the SDRP has evolved over a period of more than half a century from infrastructure-focused initiatives to a profound reimagining education. In its early stages, progress was marked by the first-order changes: equipping classrooms,

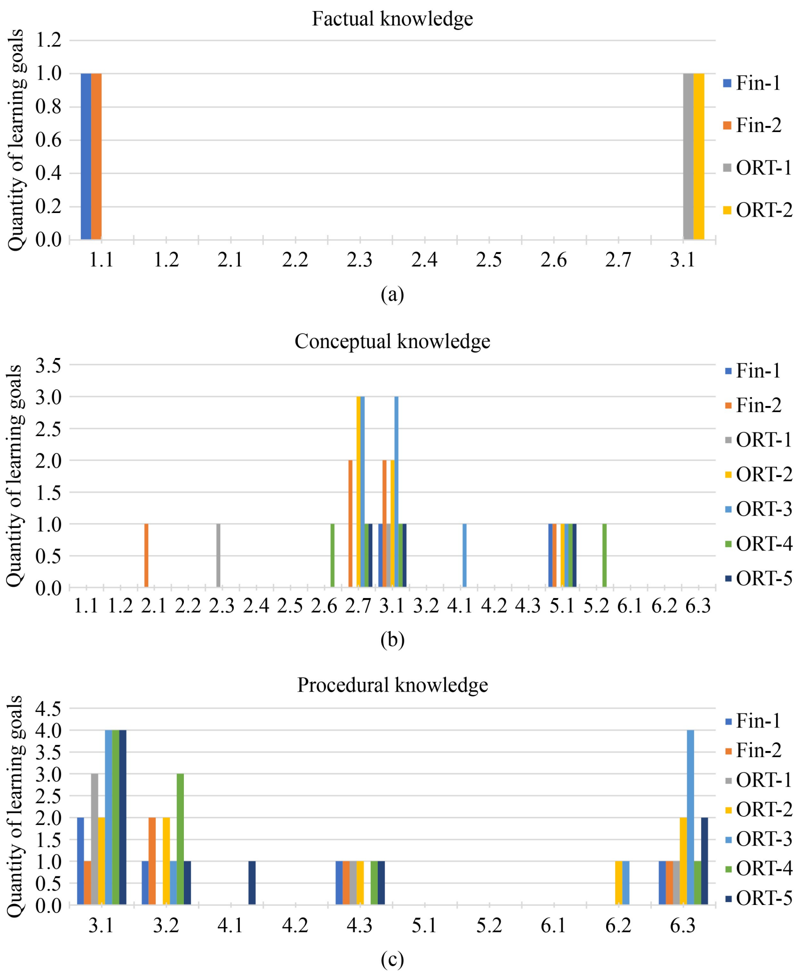

Figure 3 Distribution of the learning goals quantity according to cognitive processes (Table 3) in schools of the experimental sample in accordance with (a) factual, (b) conceptual, and (c) procedural knowledge types.

expanding connectivity, and building basic digital literacy. These efforts, while necessary, left the traditional classroom–lesson model largely intact. Today, however, SDRP has entered its advanced stage, characterized by second-order changes: a systemic shift toward PCBL that redefines goals, methods, and the organization of education purposes, structures, governance, and culture of education.

This paper has outlined a conceptual trajectory of SDRP through four digital renewal stages and explored three theoretical scenarios each reflecting different societal responses to the challenges of the AI era. Critically, the inertial path risks entrenching educational inequality under the guise of stability, while the divergent path, though responsive to individual demand, may accelerate the fragmentation of public education and erode its role as a unifying social institution. Only the transformational scenario offers a viable pathway to preserving the universal, equitable, and formative mission of secondary education in a world marked by growing complexity, technological disruption, and social uncertainty.

To responsibly govern this process, we need robust, scalable, and objective indicators capable of tracking deep pedagogical transformation, not merely the adoption of technology. These transformations can be grouped into three interrelated dimensions of change: (1) renewal of the educational process (the core operational process of the school); (2) transformation of the school's operational model (the model organizing and implementing the educational process and its renewal); and (3) development of the educational environment (the ecosystem supporting the dynamics of the two preceding processes).

General education systems belong to the class of large-scale complex systems; therefore, capturing change within each of these dimensions requires distinct, purpose-built indicator sets. The rapidly accelerating pace of digital transformation in education makes the development of a holistic, integrated indicator system increasingly urgent. The success of this endeavor depends significantly on the feasibility and reliability of using AI tools to address this challenge.

These indicators should not require direct involvement of teaching staff in data collection or initial processing. As DEEs mature, such data become increasingly accessible through publicly available digital artifacts, including curricula, syllabi, and project briefs, enabling automated extraction and analysis via AI-powered natural language processing techniques.

The main innovation of this article is the use of AI to automatically construct indicators based on public digital resources from schools in order to assess changes in SDRP at later stages of development. This approach opens a promising pathway toward the scalable, objective, and low-burden monitoring of digital transformation in education. Future work should focus on the following four aspects: (1) refining AI-driven text analysis for cross-lingual and cross-curricular applications; (2) integrating digital trace data from learning platforms to assess process renewal; (3) validating indicators through longitudinal studies across diverse educational systems; and (4) embedding these metrics into national and global monitoring frameworks, such as the GDEI.

Systematic, scenario-aware assessment is not merely a technical exercise but a safeguard for mastery-based learning. In an age where AI can both empower and stratify, public education remains one of the few institutions capable of ensuring that all young people, regardless of background, acquire the competencies and social grounding needed to navigate uncertainty and participate meaningfully in society. Without objective, evidence-based monitoring, we risk drifting into a future where digital transformation widens divides rather than bridging them.

As schools worldwide navigate the transition to the fourth stage of SDRP, robust, evidence-based indicators will be essential not only in tracking progress but also guiding policy, supporting educators, and ultimately realizing an “ideal school” in the age of AI. This will ensure that every student achieves the full range of personal, meta-subject, and subject-specific competencies needed to thrive in a rapidly evolving world. Thus, the development and validation of automated, scalable, and pedagogically grounded indicators for SDRP is not only a methodological imperative but a social and ethical necessity.

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