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SMART EDUCATION · PATHWAYS
TOWARD EDUCATION 2050

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SMART EDUCATION
PATHWAYS TOWARD EDUCATION 2050

ABRIDGED EDITION

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全球智慧教育大会

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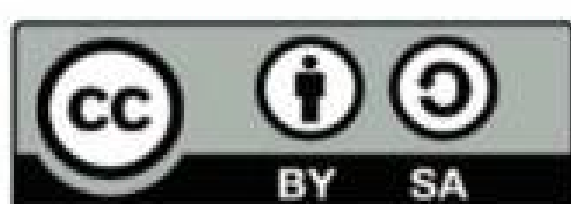Smart Learning Institute of Beijing Normal University

Smart Education: Pathways toward Education 2050

Abridged Edition

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Smart Education

Pathways toward Education 2050

Abridged Edition

Smart Learning Institute of Beijing Normal University

August 18, 2025

Preamble

In recent years, the accelerating pace of global change—driven by technological disruption, ecological crises, and growing social inequality—has prompted urgent calls to rethink the fundamental role of education in shaping the future. Aligned with this background, UNESCO launched *the Futures of Education* initiative in 2019, aiming to catalyze global dialogue and collective imagination on how education should evolve by the mid-21st century.

This initiative gained renewed significance in the wake of the COVID-19 pandemic, which not only disrupted education systems worldwide but also exposed deep structural inequalities and functioned as an unprecedented global social experiment. It revealed both the vulnerabilities and the transformative potential of education, intensifying the demand for digital innovation. In response, UNESCO released a landmark report in 2021, outlining key challenges and strategic priorities, such as the rapid evolution of technology, the widening gap between education and societal needs, and the need to redefine learning as a global common good. These themes were further reinforced during the 2022 United Nations Transforming Education Summit, where global leaders emphasized the urgency of reimagining education systems to meet the demands of a complex and uncertain future.

Over the past decade, our team has been actively contributing to the global discourse on educational transformation. This enduring commitment has been embodied through a series of milestone initiatives that integrate scholarly inquiry with international collaboration. In 2016, we initiated the US–China Smart Education Conference to promote cross-cultural exchange and collaboration across K–12, higher education, and vocational education. This endeavor laid the groundwork for broader international partnerships in the years that followed. Since 2020, in response to the global educational disruptions caused by the COVID-19 pandemic, we have hosted the Global Smart Education Conference (GSE) annually. This forum brings together diverse stakeholders from around the world to explore how digital innovation can serve as a driving force for systemic educational transformation. Working in partnership with leading international institutions, we have also conducted comparative studies on national smart education strategies and facilitated the establishment of the Global Smart Education Network (GSENet)—a growing alliance dedicated to fostering inclusive, innovative, and future-ready education systems worldwide.

Building on more than a decade of sustained research and international collaboration, we have the book, *Smart Education: Pathways Toward Education 2050*, marks a significant milestone in our collective efforts to understand and shape the future of education. Funded by the Chinese government and supported by the National Publication Foundation, it serves as a flagship publication representing the commitment to advancing global educational transformation with both academic insight and strategic vision. It brings together years of theoretical inquiry, empirical investigation, and practical experience to address a central question: *How can smart education become a shared global vision for Education 2050?*

This book positions smart education as a transformative response to the evolving demands of the intelligent era. While rooted in the principles of the Education 2030 Agenda—particularly the recognition of education as a global common good—this vision extends further, anchoring itself in the long-term horizon of 2050. It seeks to promote inclusive development, social equity, and sustainability in an increasingly digital and interconnected world. Build on this value, smart education emphasizes high-quality learning, flexible and adaptive content, and enhanced instructional efficiency. These priorities are anchored in principles of shared responsibility, mutual trust, and empathetic collaboration. Ultimately, smart education seeks to foster inclusive learning communities that support human flourishing in an increasingly complex world.

To conceptualize smart education, the book introduces two interrelated analytical dimensions. The performative features of smart education, which represent a shared vision of future learning and its goals. The constructive features, which identify the practical pathways and enabling conditions necessary to realize this vision. Structured around these core ideas, the book unfolds in four interconnected parts.

It begins by reviewing the global trends of digital transformation in education. It then refines key features of smart education, followed by a discussion of practical strategies to advance educational reform. Finally, the book offers a forward-looking landscape of smart education by 2050—drawing on the social experiments and the deep integration of technology and education to explore how smart education can align with broader national development goals and support the creation of future-ready education systems.

We would also like to express our sincere gratitude to the three distinguished scholars who contributed forewords to this book: Zhao Qinping, Academician of the Chinese Academy of Sciences; Xie Weihe, former Vice President of Tsinghua University; and Li Yongzhi, President of the China National Academy of Educational Sciences.

This book does not seek to prescribe a predetermined future, but rather invites global stakeholders to co-create it. It is intended not only as a guide, but also as a call to action—inviting researchers, educators, policymakers, and communities to explore, experiment, and collaboratively shape education systems needed for the world ahead. We hope this book will serve as a starting point for meaningful dialogue, a reference for informed decision-making, and a shared source of confidence and direction—as we collectively chart bold, inclusive, and visionary pathways to reimagine education for generations to come.

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Part I

From digital transformation to smart education

1. Global learning crisis aimd the process of digital transformation

The current political, economic, and health crises are threatening decades of progress in global education, posing increasing challenges to the realization of the United Nations 2030 Agenda for Sustainable Development. The global education crisis calls for a collective response from all countries, and it is more critical than ever to establish a unified, coordinated vision across multilateral systems.

The United Nations has emphasized that in order to address inequalities and vulnerabilities within education systems, structural transformations are needed at both national and international levels, grounded in a renewed commitment to the Sustainable Development Goals (SDGs) (United Nation, 2019). Today, education systems around the world are facing multidimensional challenges, including the erosion of equity, shortages of qualified teachers, financial constraints, the growing number of out-of-school children, and difficulties in achieving the SDGs. Together, these factors constitute a complex crisis in the education sector, eventually intensifying the global learning crisis. These mounting challenges demand urgent and effective action from governments worldwide to prevent further deterioration of education outcomes.

Global dropout rate and educational barriers

UNESCO's 2023 data reveals a worsening global education crisis, with 250 million children out of school, an increase of 6 million (UNESCO, 2023a). Globally, 10% of primary school-aged children, 14% of junior high school-aged adolescents, and 30% of high school-aged adolescents face dropout (Workercn, 2024). Sub-Saharan Africa accounts for over half of these out-of-school children, with 33% of school-aged children in low-income countries excluded, compared to 19% in lower-middle

income, 8% in upper-middle-income, and 3% in high-income countries. Economic inequality, conflict, climate change, and gender-based exclusion, particularly for girls, drive this crisis, highlighting disparities in educational resource availability. The UNESCO Institute for Statistics warns that achieving universal quality education by 2030, as outlined in the SDG 4, is unlikely at current rates. Since 2015, primary school completion has risen by only 3% (culminating to 87%), and secondary school completion by less than 5% (culminating to 58%).

Compounding the issue, 70% of 10-year-olds in low- and middle-income countries lack basic reading and numeracy skills (United Nation, 2024). In high-income countries, 70–90% of students achieve minimum reading proficiency by lower secondary school, but in most middle- and low-income countries, this drops below 60%, and in some, below 10%. Dropout rates are alarming, with nearly 60% of upper secondary students in low- and middle-income countries and 90% in low-income countries failing to complete their studies. Causes include irrelevant curricula, insufficient support for girls and poor families, lack of cultural sensitivity, and outdated teaching methods. These challenges highlight the urgent need for systemic educational reform to address the global learning crisis.

Unequal educational opportunities

Education systems around the world face another critical crisis of fairness and opportunity, with systemic inequities undermining access to quality education. UNESCO's 2023 data indicates that over 770 million young people and adults, predominantly women, remain illiterate worldwide (United Nation, 2023). In regions like sub-Saharan Africa, North Africa, and West Asia, only half of children access preschool education. The United Nations' 2019 Global Sustainable Development Report highlights persistent gender disparities, with girls in Central Asia, North Africa, West Asia, and

sub-Saharan Africa facing significantly higher dropout rates than boys (UNESCO, 2023b). Over half of the world's children and adolescents fail to meet minimum reading and mathematics standards, and UNESCO projects that by 2030, one-sixth of children aged 6–17 will remain out of school, with only 60% completing secondary education.

Furthermore, systemic exclusions based on gender, race, language, culture, and cognitive style, combined with socioeconomic disparities, disproportionately affect rural and low-income communities. Despite global commitments to universal, equitable education by 2030, three-fifths of adolescents in low-income countries cannot access secondary school, compared to near-universal enrollment (98%) in high-income countries. Enrollment gaps are stark, with less than 35% of females and 45% of males in low-income countries attending high school, compared to over 90% in high-income nations (UNESCO, 2022). OECD's PISA data further reveals that many 15-year-olds, especially in low- and middle-income countries, struggle with basic reading comprehension. Adult literacy rates also reflect disparities, with less than 75% in low- and middle-income countries and just over 55% in low-income nations, where female illiteracy exceeds 40%. Additionally, gaps in civic literacy, global competence, and social-emotional skills emphasize the need for urgent, systemic policy interventions to address entrenched inequities and advance global education equity.

Teacher shortage and low quality of education

Education must equip students with essential skills for a fulfilling life, encompassing not only literacy and numeracy but also advanced logical reasoning, creativity, and social-emotional competencies like resilience and teamwork (Word Bank, 2018). However, the World Bank's 2018 World Development Report notes that while global dropout rates have declined, increased school attendance has not consistently translated into improved knowledge and skills.

The report emphasizes that true learning, rather than mere classroom time, is critical for growth, development, and poverty reduction. Yet, misaligned curricula, poor teaching quality, and lack of culturally relevant education restrain students' creativity and curiosity, contributing to high dropout rates and inadequate preparation for modern challenges.

Teachers are pivotal to educational quality, yet UNESCO's 2024 Global Teacher Report highlights a critical global shortage, estimating a need for 44 million additional teachers by 2030 to achieve universal primary and secondary education (teacher task force, 2025). This shortage undermines educational progress worldwide. Addressing it requires comprehensive measures, including, increased investment in teacher training and professional development to ensure requisite skills; improved salaries and working conditions to enhance the profession's appeal and reduce turnover; and greater teacher autonomy and involvement in policy-making to foster innovation.

Lack of educational resources and financial pressure

The scarcity of educational resources significantly hinders global education equity and quality, with inadequate infrastructure being a critical barrier. Essential facilities like electricity, drinking water, and sanitation are absent in about one-quarter of primary schools worldwide, and only half have computers, internet access, or disability-friendly infrastructure, according to 2020 data (UNESCO, 2022). The situation is worse in least-developed countries, where resource shortages are most acute. Uneven distribution of teaching materials, technology, and teachers worsen these challenges. UNICEF reports that children from the wealthiest 20% of families receive nearly twice the public education resources compared to the poorest 20%, with low-income countries allocating 37.6% of resources to the richest and only 10.3% to the poorest (UNICEF, 2020).

Additionally, Sub-Saharan Africa faces acute resource shortages, with only 57% of high schools having electricity, 44% equipped with computers, 50% providing drinking water, and 25% offering internet access (United Nation, 2019). Teacher shortages are stark, with just 64% of primary and 50% of junior high school teachers adequately trained, well below global averages (UNESCO, 2020). Financial constraints, including limited public sector wages, hinder teacher recruitment and retention. High-income countries, despite educating only 10% of the global school-age population, account for 63% of education spending, while low-income countries, facing fiscal pressures, divert resources to short-term priorities. UNICEF notes that in low-income countries, only 11% of education funds support the poorest learners, compared to 42% for the wealthiest, deepening inequities and undermining education quality and access worldwide.

2. Emerging strategies in transforming education with digital innovation

As education systems around the world face mounting pressures from technological disruption, social inequality, and ecological challenges, the global education agenda is increasingly shifting from access alone to transformation in purpose, practice, and policy. In this context, emerging trends emphasize the need for inclusive and equitable education, enhanced learning quality, lifelong learning for all, sustainability, and innovation-driven change. These priorities are responses to global challenges and representing a shared vision for the future of education in the digital and intelligent era.

Ensuring inclusiveness and equity in education

The global commitment to equitable education has been a cornerstone of international policy since the 1990 World Declaration on Education for All, adopted by UNESCO, UNICEF, UNDP, and the World Bank, which introduced the goal of meeting universal basic learning needs.

This principle has guided national education policies worldwide. Building on the lessons of Education for All and the Millennium Development Goals, the Education 2030 Framework for Action advances this agenda through SDG 4, with a strong focus on inclusive, equitable, and quality education, as well as lifelong learning opportunities for all.

Unlike earlier frameworks, SDG 4 integrates education into broader international development and humanitarian efforts, optimizing resource allocation and fostering a unified approach. This agenda prioritizes human rights, dignity, social justice, peace, and cultural diversity, ensuring no one is left behind. The Incheon Declaration also highlights this agenda by advocating for inclusive policies and resource prioritization for marginalized groups, such as the poor, women, and ethnic minorities. This commitment drives governments to design policies that address systemic inequities, ensuring access to education for all and aligning with global development goals to create a more just and inclusive society.

Providing quality education to improve learning outcomes

The Education 2030 agenda defines its goal as ensuring inclusive, equitable quality education and lifelong learning, with "quality" as the central focus. Unlike the Millennium Development Goals' emphasis on universal primary education, Education 2030 prioritizes educational quality as the foundation for improving lives and achieving sustainable development. International organizations have issued reports highlighting this shift from quantity to quality in global education discourse. Key characteristics of quality education include enhancing education system performance to support national development, optimizing resource allocation for equitable access, addressing disparities in opportunities due to gender, region, or socioeconomic status, and adapting to complex social and cultural changes.

Quality education requires efficient resource use, equitable opportunity distribution, and responsiveness to diverse societal needs. By fostering critical thinking, innovation, and adaptability, education systems can better serve learners and communities, ensuring equitable outcomes and supporting national and global progress in an increasingly interconnected world.

Integrating the concept of sustainable development into the education system

Education for Sustainable Development (ESD) embeds sustainability principles into education to foster holistic development in cognitive, social-emotional, and behavioral domains. It equips learners with interdisciplinary skills to address sustainable development challenges, emphasizing values like respect for others, diversity, the environment, and planetary resources. The United Nations Decade of Education for Sustainable Development (ESD) (2005–2014) and subsequent frameworks highlight ESD's role in shaping values-driven education that promotes sustainable economic, social, environmental, and cultural outcomes.

ESD focuses on three dimensions, namely, the sustainability of individuals through lifelong learning and comprehensive development; the sustainability of education systems through adaptive, inclusive mechanisms; and education as a driver of sustainable development by aligning with broader societal goals. By transforming attitudes and fostering scientific knowledge and critical thinking, ESD empowers learners to make informed decisions, contributing to long-term societal and environmental sustainability while ensuring education systems remain resilient and responsive to future uncertainties.

Advocating the concept of lifelong learning within the education system

Lifelong learning is a cornerstone of modern education reform, essential in a rapidly changing world where knowledge and skills quickly become obsolete. As futurist Alvin Toffler noted,

21st-century illiteracy stems from an inability to learn, unlearn, and relearn. Lifelong learning equips individuals to manage their learning processes, integrate diverse information, and apply knowledge flexibly while fostering critical thinking and problem-solving.

Education systems must integrate lifelong learning through innovative teaching designs, such as inquiry-based and project-driven learning, which promote self-directed learning. Assessment should shift from knowledge mastery to evaluating learning motivation and potential. Beyond classrooms, leveraging technology and social resources enables learning anytime, anywhere. Creating a cultural environment that supports lifelong learning—through schools, communities, and society—is crucial to fostering adaptability and resilience, empowering individuals to navigate personal and societal challenges and drive continuous progress.

Promoting educational development through digital innovation

The 2022 United Nations Education Transformation Summit underscored the need for digital transformation to reimagine education systems. It advocated leveraging the digital revolution to provide high-quality, accessible, and contextually relevant learning resources, particularly for marginalized groups like the poor, people with disabilities, and refugees. The summit outlined three strategies: delivering high-quality digital content to ensure equitable resource access; building capacity among educators and learners to use digital tools effectively; and enhancing digital connectivity to ensure universal internet access for schools. This approach emphasizes transforming education systems, not just applying technology, to achieve high-quality public education and lifelong learning. By prioritizing digital innovation, education can bridge equity gaps, improve learning outcomes, and align with global development goals, ensuring inclusivity and sustainability in the intelligent era.

3. Smart education as a goal of educational transformation

Smart education has emerged as a strategic and systemic innovation. Building upon earlier phases of educational informatization, it represents a forward-looking paradigm shift aligned with the goals of digital transformation and global education reform. Smart education reimagines not only teaching and learning, but also educational concepts, systems, content, and governance. By harnessing the power of intelligent technologies, smart education transforms learning environments, empowers personalized and flexible instruction, and builds modern education systems that are inclusive, adaptive, and future-oriented. It supports lifelong learning and equips learners with the skills and competencies needed to thrive in a dynamic, interconnected world.

More importantly, smart education responds to global concerns around equity, quality, and relevance. Yet despite its growing adoption, stakeholders across education systems— policymakers, educators, administrators, and families—often hold differing interpretations of what smart education entails. Clarifying its core principles and characteristics is thus essential for aligning policies, fostering coherent practices, and ensuring that smart education advances equity, innovation, and sustainability in the intelligent era.

The three realms of smart education

Smart education is viewed as a system that monitors educational practices implemented by schools, regions, or governments, characterized by enhanced learning experiences, adaptive content, and improved teaching efficiency. Modern science and technologies are used to provide diversified support and on-demand services for students, teachers and parents, etc. The data of participants and learning and teaching processes are recorded and used to promote the quality and equity of education. These foundations support a more equitable and high-quality education system.

Within this system, smart education manifests across three interconnected domains: smart learning environments, technology-enhanced teaching and learning, and evidence-based governance.

Smart learning environment

Smart learning environments represent the most visible layer of smart education. They aim to enhance the overall learning experience by increasing effectiveness, efficiency, and purposeful use of digital tools. These environments can optimize cognitive engagement, encourage critical thinking, and streamline administrative functions— allowing educators to focus more on instruction. Crucially, digital tools are selected and applied in alignment with educational goals, ensuring sustainable and meaningful improvements in the learning process.

Technology-enhanced learning and teaching

Technology-enhanced teaching and learning, in combination with pedagogy, is considered important in smart education. It leverages digital tools to enable personalized learning paths tailored to individual learners' needs, interests, and progress. At the same time, it supports differentiated instruction, offering flexible teaching strategies to accommodate diverse learning types and abilities. This dimension requires a shift in traditional teacher mindsets, embracing innovation and responsiveness to student diversity.

Evidence-based governance

Evidence-based governance constitutes the systemic foundation of smart education. It emphasizes the use of data and research to inform educational policies, strategic planning, and institutional reform. Through a commitment to knowledge generation and evidence-driven decision-making, this layer drives innovation, supports professional capacity building, and ensures alignment between educational goals and implementation efforts. It is less visible to frontline educators but critical for sustainable, system-wide transformation.

Recognizing the key features of smart education

As technology becomes increasingly embedded in educational practice, smart education is taking shape through a set of distinctive features that reflect both its visionary goals and its practical strategies. These features have gradually evolved from the internal development of smart education's three core realms: the learning environment, pedagogical models, and system-level governance. They can be understood through two interconnected dimensions, the performative and the constructive, which together provide a coherent framework for advancing educational transformation in the digital age. The features of smart education can be understood through two interconnected dimensions that bridge vision and practice.

The performative features express a collective aspiration for the future of education. They outline an ideal learning ecosystem centered on the learner, supported by comprehensive assessment systems, intelligent and ubiquitous learning environments, a culture of continuous improvement, and a strong commitment to equity and inclusion. These features reflect global consensus and provide directional and stable guidance for reform. Complementing this vision, the constructive features define the practical strategies required to realize it. They emphasize the importance of building student-centered learning communities, enhancing teacher development, promoting the ethical application of technology, ensuring the sustainability of educational reform, and fostering collaboration across multiple sectors. Together, these dimensions provide a coherent roadmap for advancing educational transformation in the digital era.

Figure 1. Definition of smart education features

Source: Huang, R.H., Liu, D.J., Kanwar, A.S., Zhan, T., Yang, J.F., Zhuang, R.X., Liu, M.Y., Adarkwah, M., Li, Z.S. (2024). Global Understanding of Smart Education in the Context of Digital Transformation. Beijing: Global Smart Education Network and Smart Learning Institute of Beijing Normal University

Part II

Performative features of smart education as a shared vision

Box 1.

Smart education, as a transformative response to the digital age, redefines learning through advanced technologies, fostering innovative, equitable, and adaptive educational systems. Its performative features provide a cohesive framework for global education transformation, aligning with principles of consensus, directionality, and stability. Student-centered teaching and learning represent the intrinsic values of humanistic education, manifested in teaching structures that promote learner agency. Innovative learning assessments represent the integration of mass education with personalized cultivation. Ubiquitous smart learning space provide support for learners to connect across various contexts. Culture of continuous improvement ensures the orderly progression of educational reform and development. Upholding inclusivity and equity in learning opportunities is a universally endorsed principle in the international education community. Furthermore, smart education incorporates principles of lifelong learning, aligning with global sustainability goals and the imperative for continuous personal and professional development.

4. Student-centered teaching and learning in digital environments

Student-centered learning is an instructional approach that places the student at the center of the learning process, emphasizing their active participation, engagement, and autonomy (Haiyan, 2017). Rooted in Dewey's notion of child-centered education, this concept positions students as the core focus of the teaching process, empowering their agency and fostering self-directed learning and creativity (Margonis, 2009). This approach aims to enhance learning transfer and prioritize student outcomes, providing a stark contrast to the traditional teacher-centered instructional model. The increasing integration of technology into classrooms has significantly influenced the evolution of teaching methods, educational models, and student learning environments. Educational practices must facilitate diverse pathways for authentic learning experiences beyond the traditional classroom, promoting inquiry, discussion, and meaningful connections between concepts.

Strategic use of technology, when aligned with educational principles, is essential for the holistic development of students.

Transformation of educational concepts shaped by intelligent technologies

As technology continues to drive educational innovation, student-centered teaching principles have gained widespread recognition. However, the rapid advancement of intelligent technologies is prompting deeper transformations in traditional educational paradigms. These technologies not only enhance student-centered approaches but also fundamentally reshape knowledge production and dissemination, giving rise to new educational concepts. The shift moves education from content-focused to competency-based, and from rigid teaching processes to dynamic, personalized learning pathways. With AI expected to revolutionize teaching and learning within 5-10 years, educators must thoughtfully integrate these tools to ensure quality education. Figure 2 shows four areas affected by technological evolution.

Knowledge creation beyond experts

Knowledge is now co-created through interactions between humans and AI, giving rise to forms of "dark knowledge", insights that may exceed human understanding. Knowledge can be categorized into three types: factual (what), procedural (how), and metacognitive (how we understand and use knowledge). Increasingly, the focus is shifting toward the latter two. Rather than being static and fixed, knowledge is becoming dynamic, and continuously shaped through collective meaning-making.

Learning connected to digital environments

Learning occurs in AI-enhanced environments that support personalized, lifelong, and self-driven development. AI diversifies learning inputs, pathways, and feedback but doesn't alter the core cognitive process. Goals shift from external compliance to intrinsic motivation, emphasizing societal contribution and holistic growth. Future learning will prioritize adaptive, experiential, and embodied approaches, distinguishing human cognition from AI.

Figure 2. The expected changes in education for the future
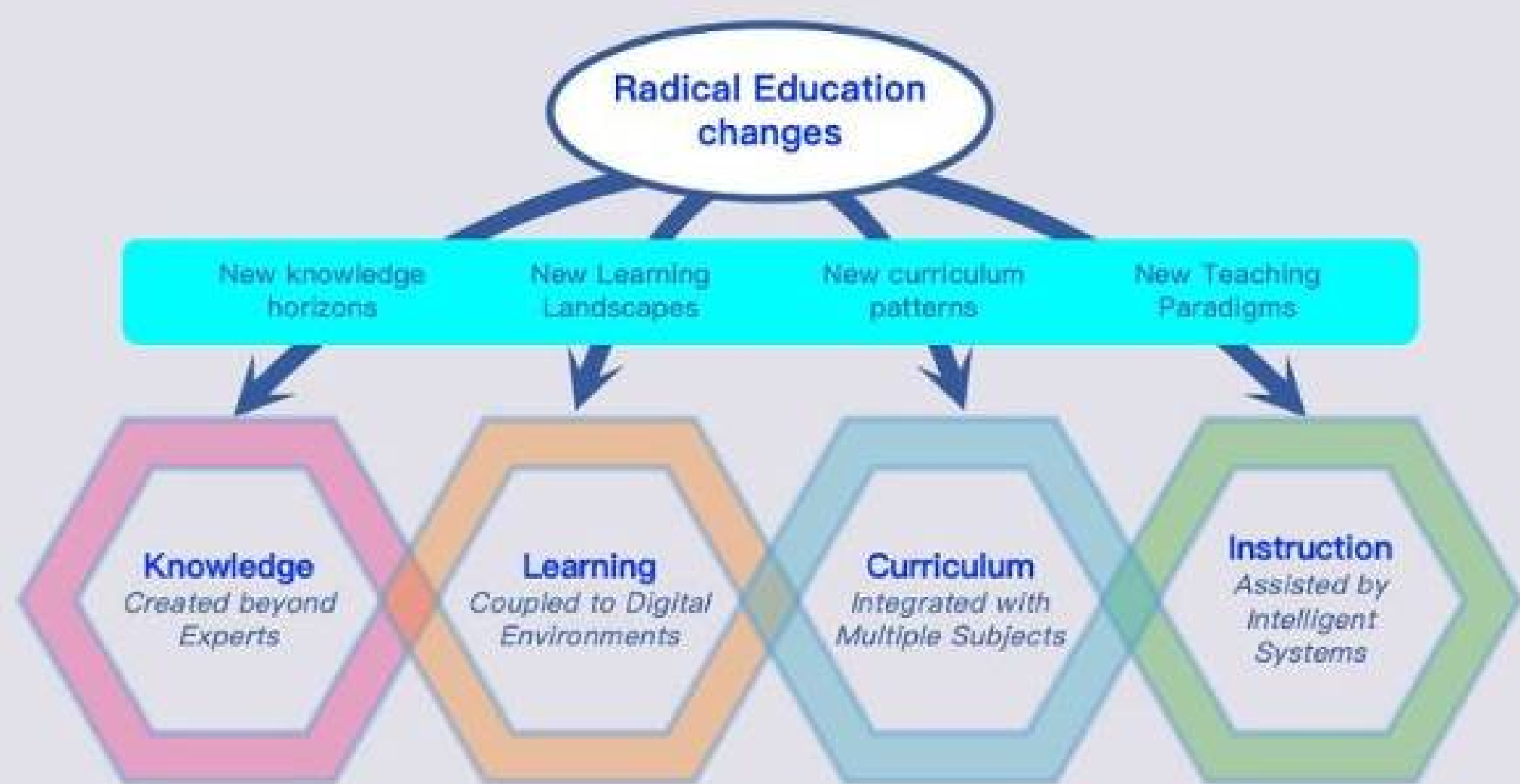
Source: Huang, R. H., et al. (2023). *Artificial Intelligence and the Development of Future Education.* Beijing: Science Press.

Curriculum integrated with multiple subjects

Curricula transition from knowledge-based to human-centric, fostering wisdom and problem-solving. Content becomes interactive, blending science, technology, culture, and life experiences through AI mediation. Personalized "one-student-one-timetable" systems replace standardized models, supported by AI-generated knowledge maps and learner profiles. Cross-border, shared resources enhance educational equity and accessibility globally.

Instruction assisted by intelligent systems

Teaching leverages AI to empower student agency while nurturing critical thinking and values. Educators evolve from knowledge transmitters to learning designers, mentors, and emotional guides. Hybrid models combine diverse knowledge forms, mediums, and settings, strengthening interaction and understanding.

This transformation underscores a future where intelligent technologies and human expertise synergize to create adaptive, inclusive, and meaningful educational experiences.

Learning behaviors in tech-enabled environments

The widespread integration of information technologies—from early multimedia tools to modern AI, 5G, big data, and virtual reality—has profoundly reshaped classroom dynamics and teaching-learning interactions. These technologies have enabled new pedagogical possibilities, optimizing educational processes by transforming relationships among teachers, students, content, and methods. As digital tools become embedded in instruction, they generate extensive behavioral data, offering insights to refine teaching strategies through analytics.

Technology's educational value lies not in its capabilities alone but in how it accommodates pedagogical needs. In tech-enhanced classrooms, teacher and student interactions with tools create digital traces that reveal behavioral patterns. Key aspects include:

Teacher roles

Content Presentation: Using multimedia (videos, animations) to deliver knowledge.

Interaction: Facilitating peer, teacher-student, and human-machine exchanges via collaborative platforms.

Guidance: Leveraging AI tutors and digital resources to scaffold learning (e.g., reading support, automated feedback).

Engagement: Designing gamified activities or real-world problem-solving to motivate learners.

Classroom Management: Deploying tools for time/behavior tracking and resource organization.

Student roles

Exploration: Utilizing technology for research, data analysis, and hypothesis testing.

Communication: Engaging in discussions and teamwork through digital platforms.

Creation: Constructing tangible outputs (e.g., prototypes, digital artifacts).

Expression: Showcasing ideas via creative tools (video, music, visual arts).

Self-Management: Employing apps for task/time management and conflict resolution.

Together, these evolving roles and environments underscore the imperative to reimagine education not merely as a site of knowledge transmission, but as a dynamic ecosystem where learners and educators co-construct meaningful and adaptive learning experiences.

5. Rethinking learning assessment for entering the intelligent era

Learning assessment is crucial in the educational process as it influences the behaviors of both teachers and students, leading to enhanced engagement during instructional activities. Teachers are encouraged to provide guidance and support, implement adaptive strategies, and utilize learning analytics to deliver personalized and timely feedback to students. Concurrently, students are motivated to collaborate with teachers in setting learning goals and, with appropriate guidance, select effective methods to demonstrate their acquired knowledge and skills.

Learning assessment methods should be diversified and categorized as Assessment of Learning, Assessment for Learning, and Assessment as Learning to facilitate holistic student growth. "Assessment of Learning" involves summarizing interim learning outcomes, requiring teachers to analyze students' learning progress and judge their performance and achievements.

"Assessment for Learning" seeks to gather evidence for learning advancement, prompting teachers to collect learning process data promptly and semi-automatically, adjust teaching strategies, and enhance instruction.

"Assessment as Learning" aims to teach students self-evaluation skills during their learning journey, necessitating teachers to provide diverse learning and showcasing opportunities to encourage self-assessment and self-development (UNESCO IITE, 2022).

Societal consensus on holistic student development in the digital era

In an era characterized by rapid technological advancements and globalization, educational goals have expanded to encompass a holistic approach to student development. Aligning educational goals with the societal consensus on student development in the digital age involves harmonizing educational practices with the broader expectations and needs of society, as reflected in contemporary educational discourse. This consensus emphasizes the integration of technology, personalized learning, and the development of both cognitive and socio-emotional skills to prepare students for a rapidly evolving digital landscape. It is crucial to foster a shared societal understanding and commitment to nurturing students who are not only academically proficient but also socially aware, adaptable, and prepared to make meaningful contributions to their communities and the global society.
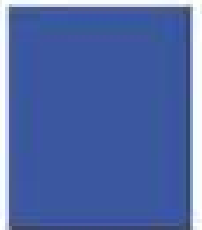
Comprehensive assessment of student learning

Assessment of learning involves evaluating students' cognitive, emotional, and social development at critical stages, providing a comprehensive view of their progress. This means incorporating diverse methods such as real-time feedback through AI-driven tools, which assist in identifying academic strengths. Student learning outcomes are measured against nationally specified performance standards and standardized tests to ascertain the knowledge and skill level of students. By integrating multifaceted assessment strategies, educators can gain a holistic understanding of each student's development and provide timely feedback to improve student learning and boost their graduation rates. This comprehensive approach not only measures academic achievements but also ensures that students are developing the emotional intelligence and social skills necessary to succeed in an interconnected world.

Assessment for learning and technology-mediated continuous feedback

Assessment for learning is an integral component of contemporary educational practices, enabling the provision of continuous feedback to students and educators. By leveraging advanced technological tools and educational software, this approach enables real-time monitoring of student performance, facilitating timely interventions and personalized learning pathways. By identifying and addressing learning gaps promptly, educators can tailor their instructional strategies to meet the diverse needs of each student. This method not only enhances student engagement and achievement but also promotes a deeper understanding of the subject matter. Through the integration of data analytics and adaptive learning platforms, Assessment for Learning ensures a responsive and effective educational experience, aligning with the global standards for quality education.

Assessment as learning and student self-reflection for lifelong learning

Assessment as learning emphasizes the role of students in their own learning process, encouraging self-reflection and fostering a sense of responsibility for their educational journey. This approach aims to develop self-directed learners who can thrive in the digital age. By engaging in regular self-assessment and reflection, students become more aware of their strengths and areas for improvement, empowering them to set personal learning goals and take proactive steps towards achieving them. Digital tools and platforms further support this process by providing students with access to resources, feedback, and progress tracking. Consequently, Assessment as Learning not only enhances student autonomy and motivation but also prepares them for lifelong learning in an ever-evolving digital landscape.

6. Ubiquitous and smart learning spaces

Learning environments are integral to the teaching and learning process, serving as crucial contexts that facilitate educational activities. Smart learning environment represents a sophisticated evolution of traditional digital learning settings, seamlessly merging physical and virtual elements to provide personalized learning support and services based on individual learner characteristics. The development of such smart learning environment encompasses five key aspects: ubiquitous and secure network access, trustworthy learning tools, customized learning resources, adaptive learning spaces, reliable and robust digital terminals, and the effective integration of these components to enhance the overall educational experience.

Reliable network access

Ubiquitous and reliable network access is a fundamental prerequisite for modern education, ensuring that students and educators can connect to learning resources anytime and anywhere, whether through fixed or mobile networks through fixed or mobile networks. Successful twenty-first-century schools are characterized by integrated internet access, including domain registrations and mobile broadband subscriptions tailored for pedagogical purposes. Reliable internet connectivity and robust cybersecurity measures are essential for protecting sensitive data and maintaining the integrity of the educational process. By providing seamless and secure access to digital tools and content, educational institutions can support continuous learning and collaboration, irrespective of geographical and temporal constraints.

Trustworthy learning tools

Trustworthy learning tools are essential in providing a reliable and effective educational experience. These tools ensure accuracy, consistency, and fairness in assessments, fostering trust among students, educators, and stakeholders. By leveraging secure and validated digital platforms, educators can deliver content and assessments that meet high standards of integrity. This trustworthiness is crucial for building confidence in the learning process and for ensuring that the educational outcomes are credible and respected by all parties involved.

Customized learning resources

Customized learning resources allow educators to tailor instructional materials to meet the specific needs and preferences of individual students. In the customized learning environment, students utilize specific learning resources specifically designed to address their diverse learning needs. By utilizing data-driven insights and adaptive technologies, educators can create personalized learning experiences that address diverse learning styles and paces. Customized resources enhance student engagement, motivation, and achievement by providing relevant and meaningful content that resonates with each learner's unique context and goals.

Adaptive learning space

An adaptive learning space is designed to be flexible and responsive to the evolving needs of students and educators. It incorporates advanced technologies and pedagogical strategies that adjust the learning environment in real-time based on student interactions and feedback. This dynamic setup fosters an inclusive and supportive atmosphere where students can thrive, facilitating active learning, collaboration, and innovation. Adaptive learning spaces are crucial for accommodating diverse learning preferences and promoting effective educational outcomes.

Robust digital terminal

Robust digital terminals, such as laptops, tablets, and smart devices, are essential for both teachers and students to access and interact with digital learning environments. These devices must be durable, user-friendly, and capable of supporting a wide range of educational applications and activities.

Process of smart learning

Smart learning is composed of five interrelated and interactive core elements, namely technology empowerment, motivational stimulation, adaptive learning, effective learning, and self-directed learning. Together, these elements form a dynamic process that underpins the development of smart learning.

Figure 3. Process model of smart learning
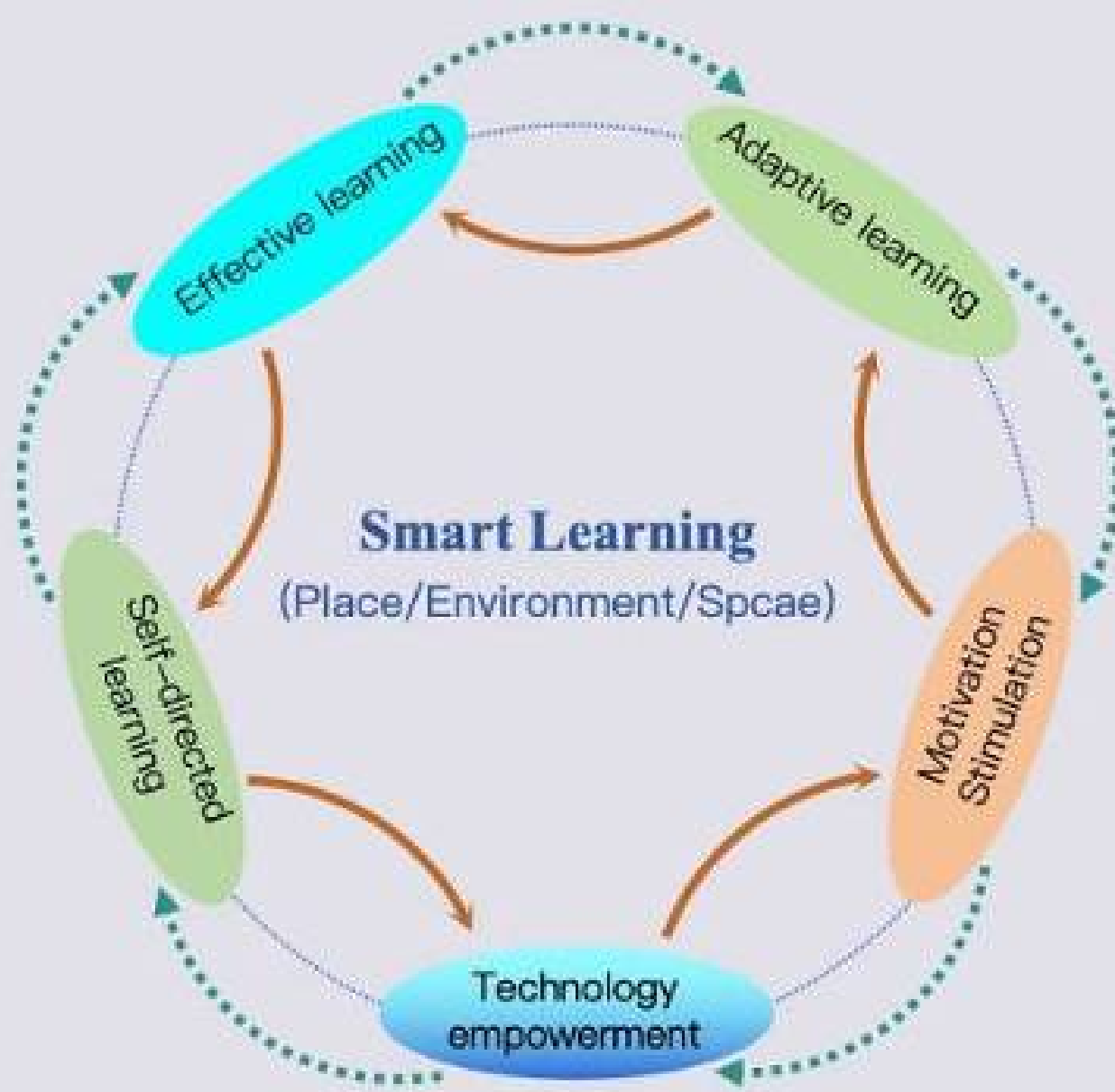
Source: Huang, R. H. (2024). The internal logic of how digital technology empowers contemporary educational transformation: From environment and resources to digital pedagogy. *Basic Education in China,* (01), 10–17.

Technology empowerment

Technology serves as the foundational support for smart learning. By integrating innovative tools and digital technologies, it ensures flexibility and accessibility within learning environments, enabling learners to achieve higher levels of efficiency and engagement.

Motivational stimulation

Motivational stimulation plays a critical role in sustaining learners' interest and intrinsic drive. Through mechanisms such as goal-setting, incentive systems, and contextualized instructional design, this element enhances learners' enthusiasm, initiative, and sustained participation in the learning process.

Adaptive learning

Adaptive learning emphasizes responsiveness to individual differences, learning progress, and changing social contexts. By leveraging data-driven strategies, it facilitates personalized learning experiences that align with each learner's needs and developmental trajectory.

Effective learning

Effective learning focuses on the importance of selecting and applying appropriate learning strategies and methodologies. This includes approaches such as meaningful learning, inquiry-based learning, and collaborative learning, all aimed at promoting deep knowledge acquisition, transfer, and application.

Self-directed learning

Self-directed learning is a defining feature of smart learning. It highlights learners' self-efficacy and agency, encouraging them to take initiative in planning, decision-making, monitoring, managing, and evaluating their own learning processes. These self-regulatory behaviors help sustain and optimize learning performance over time.

7. Culture of continuous improvement in educational digital transformation

Educational culture is foundational for guiding educational reform and should permeate all aspects of the education system. At the school level, continuous improvement is essential to adapt to educational changes. Effective school improvement reshapes the internal environment to achieve educational goals. To achieve practical enhancements and introspection, school reform requires rigorous research and active student involvement. Technology use in education should be driven by achievable goals and align with educational principles. Additionally, teacher training should adhere to scientifically sound instructional design principles.
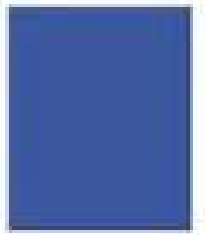
Strengthening collaboration among universities, research institutions, schools, and other entities is crucial for fostering an open and efficient research community, promoting educational advancements.

Cultural lag in addressing systemic educational reform

The transformative impact of technologies like AI, big data, and the internet is reshaping societal and educational paradigms, outpacing cultural adaptation. William Ogburn's concept of "cultural lag" aptly describes this phenomenon, where material advancements (technology and tools) outstrip cultural adjustments, creating a lag that hinders systemic reform.

In education, this manifests as a disconnect between rapid technological progress and slower cultural shifts in values, practices, and institutional frameworks. Traditional educational models, rooted in standardized teaching and assessment, resist the adoption of smart education concepts like data-driven evaluation and personalized learning. Educators often cling to familiar practices, and institutional frameworks lack clear guidelines for integrating technology, resulting in fragmented reforms and inefficiencies. Overcoming this lag requires deep cultural reconstruction, aligning educational values with technological advancements to foster a cohesive, adaptive educational ecosystem that supports systemic change.

Cultural atmosphere in educational digital transformation

Educational digital transformation extends beyond technological upgrades to encompass cultural reconstruction, shaping a proactive, adaptive cultural atmosphere. This atmosphere, defined by shared values, beliefs, and practices, determines how effectively technology integrates into education and influences stakeholders' acceptance and innovation. Cultural lag often impedes reform, as traditional values resist digital learning paradigms.

Schools must foster learner-centered cultures, families must shift from supervisory to supportive roles, and society must transition from external support to co-building educational ecosystems. Achieving this requires consensus among schools, families, and society, aligning cultural values with technological innovation to create a dynamic, inclusive atmosphere that supports sustainable transformation.

School culture: from knowledge transmission to technology-driven learning ecosystems

School culture must evolve from teacher-centric, standardized models to learner-centered, technology-driven ecosystems. Digital transformation decentralizes knowledge transmission, promoting personalized, inquiry-based learning. However, challenges like limited teacher digital literacy and rigid governance structures hinder deep integration. Schools must build professional development systems, data-driven governance frameworks, and flexible learning environments to break path dependencies, aligning culture with technological advancements to foster innovative, adaptive educational ecosystems.

Family culture: from traditional education to digital learning support

Family culture, traditionally tied to standardized education and exam-driven success, often resists digital learning. Digital transformation requires families to embrace diverse learning paths and shift from supervisory to supportive roles, guiding digital literacy and resource management. The digital divide exacerbates inequities, as resource-limited families struggle with access and digital skills. Policy support and community initiatives are essential to enhance parental digital literacy, ensuring equitable participation in digital education ecosystems.

Social culture: from external support to co-building educational ecosystems

Social culture must transition from providing external resources to actively co-building educational ecosystems. This involves integrating policy, market, and community efforts to promote equity, lifelong learning, and collaborative innovation. Challenges include ethical concerns like data privacy and algorithmic bias, requiring robust governance frameworks. Social consensus on technology's role in education must balance innovation with fairness, ensuring digital transformation supports inclusive, sustainable educational development.

Multi-stakeholder collaboration in embracing change culture

Digital transformation demands a collaborative culture among schools, families, and society, breaking traditional boundaries to foster shared goals. Schools must integrate social resources, families must engage actively, and society must drive policy and innovation. Ethical governance, addressing data privacy and algorithmic fairness, is critical to maintain trust. This collaborative culture ensures technology serves learner development, promoting equity and innovation across the educational ecosystem.

Key elements of advancing a continuous improvement culture

Building a continuous improvement culture requires balancing theoretical guidance with practical exploration. Six key elements drive this process:

Clear Goals: Setting specific, measurable objectives focused on student outcomes and efficiency.

Flexibility: Adapting to technological and social changes through iterative solutions.

Time Support: Allocating time for experimentation, collaboration, and evaluation.

Data-Driven Capacity: Enhancing data literacy to support evidence-based decisions.

Evaluation Mechanisms: Implementing ongoing assessments for dynamic improvement.

Leadership: Driving vision, empowerment, and resource allocation for cultural transformation.

These elements ensure a scientific, sustainable approach to educational improvement.

8. Commitment to inclusion and equity in technology-enhanced education

Inclusiveness and equity are fundamental pillars of high-quality education. Smart education must address the needs of both students and educators, promoting diverse representation in decision-making processes. Advancing inclusive, equitable, and resilient education requires involvement from various spheres, including learning, culture, and society. This collective effort aims to achieve a plan called "zero refusal, zero exclusion" to minimize instances of exclusion within and beyond the education system.

Overcoming obstacles that impede students' access to educational opportunities and engagement is imperative. Equal access to education should be ensured for every eligible child. Customizing classrooms and providing instructional support for students with special needs fosters their integration into mainstream classrooms. Embracing and appreciating diversity among students and families and viewing individual differences as opportunities for enhancing learning and driving educational innovation, are pivotal principles (UNESCO, 2019).

Right to education for all

Guaranteeing the right to education for all is a fundamental principle that underpins high-quality education systems. Every child, regardless of background, socioeconomic status, or geographic location, must have access to educational opportunities. The Right to Education for All movement also seeks to eliminate gender
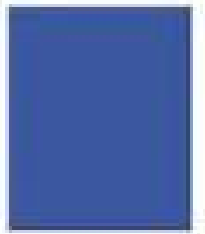
disparities in education. This commitment is essential for fostering an inclusive and equitable learning environment where all students can thrive. Upholding this right involves eliminating barriers to education and promoting social justice, ensuring that no child is left behind.

Adequate support and resources for students with special educational needs

Providing adequate resources to support students with special educational needs is crucial for their successful integration into mainstream classrooms. Customized instructional support, specialized equipment, and trained personnel are necessary to meet the diverse needs of these students. A universal design for learning approach ensures school infrastructure, materials, and resources are adapted to students to eliminate inclusion barriers. By ensuring that resources are allocated effectively, schools can create an inclusive learning environment that empowers all students to reach their full potential. This approach not only enhances educational outcomes but also fosters a sense of belonging, equity, and equality within the school community.

Accommodating student and family diversity

Embracing and accommodating the diversity of students and their families is vital for creating an inclusive educational environment. This advocates for school policies and practices to tackle all forms of discrimination and ensure adequate support for disadvantaged or marginalized students. Recognizing and valuing the unique cultural, linguistic, and socioeconomic backgrounds of students enriches the learning experience for all. Schools should implement policies and practices that celebrate diversity, promote cultural competence, and encourage inclusive

participation. This fosters a supportive and respectful atmosphere, enhancing student engagement and academic achievement while preparing students for a diverse and interconnected world.

Addressing regional differences with tailored approaches

Addressing regional differences with tailored educational approaches ensures that the unique needs of various communities are met. Educational strategies should be adapted to local contexts, considering economic conditions, cultural practices, and specific challenges faced by different regions. By implementing targeted interventions and leveraging local resources, schools can provide relevant and effective education that resonates with the community. This promotes equitable access to education and supports sustainable development and resilience within the education system.

Part III

Constructive features of
smart education in sustainable pathways

Box 2.

Smart education embodies constructive features that support its systematic development, aligned with principles of operability, phasing, and diversity. These features offer both a practical pathway and a strong theoretical foundation for driving educational transformation. Constructive features are explored through five key dimensions. Firstly, fostering global mindsets in student learning communities emphasizes the importance of digital and globalized social learning, focusing on how digital culture shapes students' social cognition and interaction. Secondly, the national priority for teacher professional development highlights the need for enhancing teachers' digital skills through structured training, clear entry standards, and guaranteed resources to ensure their leadership in educational reform. Thirdly, ethical technology use and regulation in education addresses concerns about the responsible use of intelligent technologies, promoting ethical norms and social responsibility to avoid misuse and safeguard equity. Fourthly, sustainable educational planning calls for education policies that align with the goals of long-term development, supported by evolving infrastructure, targeted resource systems, and integration of emerging technologies in line with educational principles. Lastly, the fifth dimension is about effective partnership among stakeholders in educational transformation. This emphasis on multi-stakeholder cooperation is to allow the integration of social, policy, and technological innovations. Together, these dimensions define smart education's mission and provide a systematic roadmap for its high-quality development in the intelligent era.

9. Fostering global mindsets in student learning communities

Digital technologies have fundamentally reshaped human interaction by creating virtual spaces that transcend physical and temporal boundaries. These technologies redefine the nature of communities, enabling dynamic, networked relationships that differ from traditional social structures. In digital environments, individuals can construct new identities and modes of expression, but such virtualization also introduces risks of alienation, superficiality, and weakened social bonds. To address these tensions, Jürgen Habermas's theory of communicative rationality offers a compelling framework.

It emphasizes authentic, reciprocal communication as a means to rebuild mutual understanding and counteract the instrumental rationality often embedded in technology. Habermas situates interaction within a lifeworld composed of three dimensions: culture, society, and individuality—each vital for sustaining meaning, norms, and agency. This conceptual foundation informs the architecture of digital society, structured around digital culture, individual space, and social order (see Figure 4).

Impact of digital culture on social cognition in student communities

Digital culture refers to the shared cognitive foundation that underpins social interaction in the digital age. Within a digital environment, individuals are required to develop awareness of

digital tool usage and the ability to apply technologies effectively, in order to adapt to ongoing technological changes and ensure their continued relevance and adaptability in digital contexts.

Tool awareness

Individuals are expected to possess the awareness, understanding, and ability to recognize and apply various digital tools, technologies, and resources. A competent digital citizen is capable of using digital tools in a lawful and secure manner and engaging with digital technologies appropriately and responsibly to participate in social interactions and contribute to the harmonious development of interpersonal relationships.

Digital literacy

The ability to safely and appropriately access, manage, understand, integrate, communicate, evaluate, and create information through digital technologies constitutes a set of interrelated digital skills.

Digital self-efficacy

An individual's confidence in using digital tools, responding to technological changes and challenges, and their self-efficacy in achieving goals within digital environments.

Figure 4. Digital society Culture-Space-Social (CSS) framework for student communities
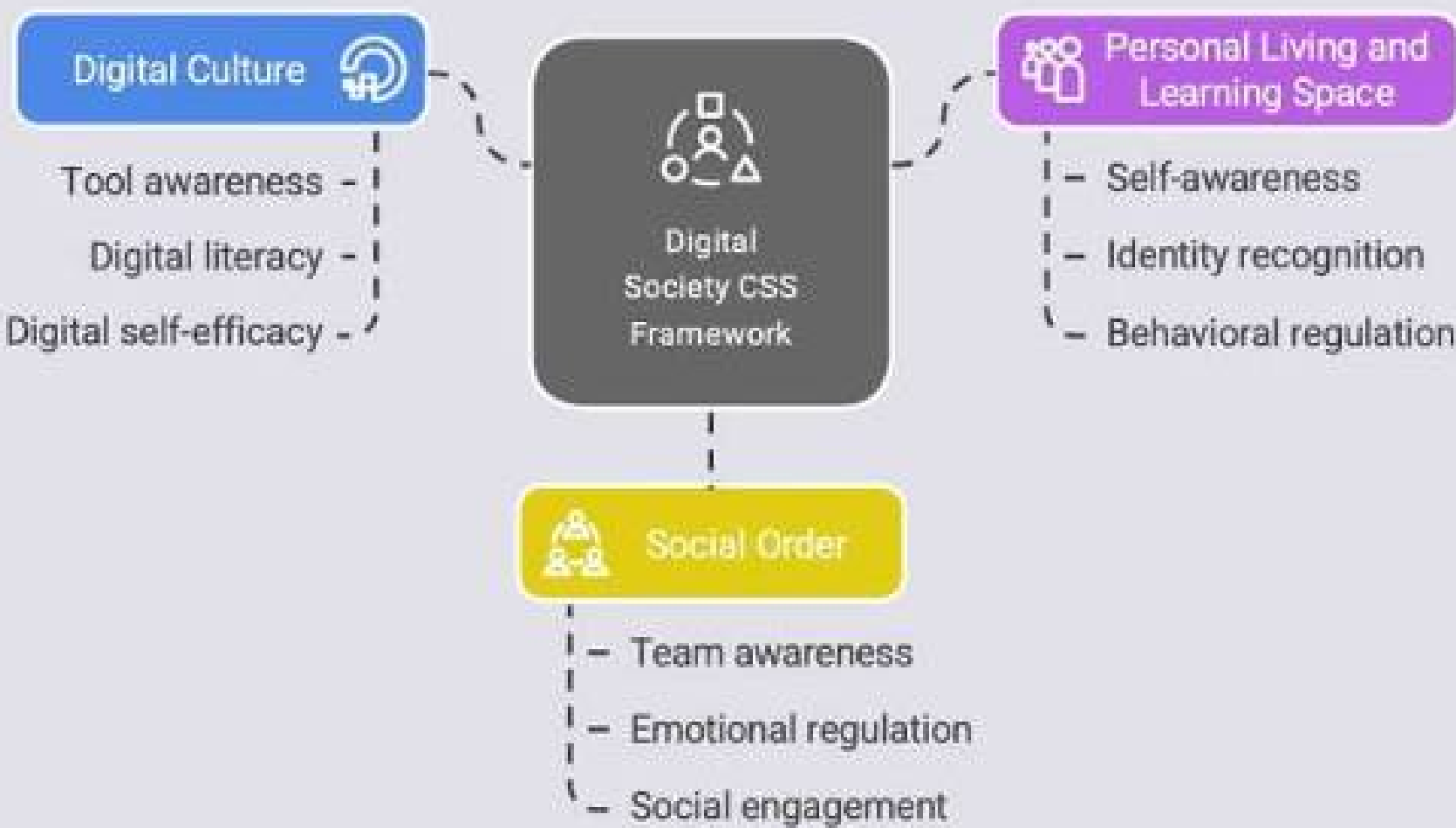
Source: Huang, R. H., Liu, M. Y., Hu, Y., & Guo, J. (2024). An analysis of student community interaction behaviors in the context of the digital society. *e-Education Research*, 45(1), 5–12, 35.

Personal living and learning space within social communities

The personal agency of community members serves as a driving force for the development and continuity of the community. A key characteristic of individual autonomy is the possession of self-awareness. Individuals with independent self-awareness establish a sense of identity through their interactions with others and the world.

Self-awareness

Self-awareness shapes personal development and decision-making, allowing students to define their roles in digital communities. Digital platforms enable new forms of self-expression, such as crafting online identities through social media. This digital self-awareness enhances students' ability to articulate interests, connect with peers, empathize with others, and protect privacy, fostering meaningful interactions and robust social networks.
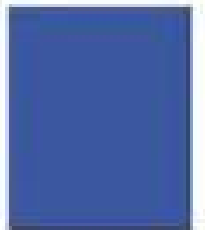
Identity recognition

Identity formation occurs through social interactions, where individuals negotiate their roles and values. In digital communities, identity fosters belonging, cohesion, and effective communication. Students develop self-concepts through reflective engagement, aligning personal goals with community norms to build supportive, collaborative networks that enhance social integration.

Behavioral regulation

As individual agency grows, behavioral restraint becomes essential to maintain community harmony. Self-regulation ensures compliance with social norms, preventing disruptive actions like cyberbullying or misinformation. Responsible behavior fosters trust, encourages thoughtful communication, and supports a positive digital environment, enhancing community cohesion.

Social order for sustainable student communities

Social order underpins sustainable student communities, fostering trust and collaboration. It regulates interactions, maintains relationships, and promotes unity, requiring students to develop cultural understanding, emotional skills, and active participation.

Team awareness

Team Awareness can enable students to recognize and respect diverse cultural norms and values, fostering empathy and reducing conflicts. This awareness encourages inclusive behaviors, supports social justice, and creates open, collaborative environments where diverse perspectives are valued, strengthening community bonds.

Emotional regulation

Emotional competence, as defined by the Collaborative for Academic, Social, and Emotional Learning (CASEL), involves managing emotions, building relationships, and making ethical decisions. Social-emotional learning (SEL) programs integrate these skills into education, encouraging students to empathize, resolve conflicts, and maintain positive interactions, enhancing their ability to navigate complex digital social environments.

Social engagement

Social engagement is critical for student development, which emphasizes responsibility and engagement. UNESCO highlights the importance of fostering civic responsibility through education, encouraging students to engage in public affairs and build connections between self and society. Active participation drives innovation, strengthens community cohesion, and supports sustainable development.

10. National priority for teacher professional development

Teachers play a central role in implementing smart education and are essential to its success. The advancement of smart education necessitates a teaching workforce proficient in digital literacy and advanced pedagogical skills. Merely investing in digital technology equipment and resources is insufficient for genuine transformation; government-led and funded initiatives like pre-service teacher training, continuous professional development, and ongoing learning support are pivotal for effective educational digital transformation.

The priority of teacher professional development

Since the turn of the 21st century, global consensus has solidified around the pivotal role of teachers in education systems, recognizing their quality as a key determinant of learning outcomes and the realization of equitable, inclusive education. The urgency of prioritizing teacher development stems from their critical role in driving digital transformation, building intelligent societies, and addressing future educational challenges.

Teachers as crucial agents of digital transformation

Teachers are not passive adopters but central agents of digital transformation, reshaping pedagogy, instruction, and learning environments. Their effectiveness relies on strong professional development, digital literacy, and innovative practices. As facilitators, designers, and innovators, they align technology with educational goals and ensure it leads to meaningful outcomes. Research confirms that teacher quality is the most impactful school-based factor in student achievement. Without policy support and adequate training, digital reforms risk failure.

Teaching as a uniquely vital profession in intelligent societies

In intelligent societies, teaching holds a uniquely vital role—not only transmitting knowledge but shaping students' values and the ethical foundation of society. While AI may process information efficiently, education's core—emotional intelligence, critical thinking, and moral judgment—remains deeply human. Teachers guide students' personal growth and social responsibility with context-aware insight no machine can replicate.

Teachers' forward-looking capacity for future education

Amid rapid technological and societal shifts, teachers' forward-looking capacity is essential for building resilient, future-ready education systems. As education becomes more personalized, intelligent, and interdisciplinary, teachers must possess advanced digital and pedagogical skills to navigate uncertainty. Without proactive development, they risk falling behind, weakening both teaching quality and policy implementation. Particularly in underserved areas, teacher growth is key to bridging digital divides and ensuring inclusive learning. A strategic support plan—focused on digital literacy, ethics, and continuous professional growth—is vital to empower teachers as drivers of equitable and sustainable educational transformation.

Inquiry-based technology application for pre-service teachers

Pre-service education lays the foundation for future-ready teachers in intelligent societies. As teaching shifts toward tech-rich and hybrid environments, training must move beyond tool demonstration to inquiry-based models rooted in Dewey's philosophy. This approach emphasizes problem-solving, critical reflection, and collaborative learning, enabling pre-service teachers to explore technologies in authentic contexts. By focusing on the logic, data mechanisms, and pedagogical alignment of digital tools, it fosters technical literacy, innovation, and risk awareness. Such training equips teachers to navigate intelligent, equitable education systems with confidence and competence.

Experiential tech-enabled training for in-service teachers

Experiential learning, emphasizing the interplay between experience and cognition, is ideal for in-service training, enabling teachers to internalize digital skills through immersive, reflective practice. Rooted in Dewey's theory of experiential continuity, this approach views knowledge as derived from transforming experiences through a cycle of concrete experience, reflective observation, abstract conceptualization, and active experimentation. It prioritizes authentic, immersive contexts where teachers engage deeply with technology, fostering skill acquisition and critical reflection. Digital tools like virtual reality and AI enhance experiential training, breaking traditional constraints and enabling immersive, data-driven learning environments that bridge theory and practice. Experiential training should incorporate perception learning (preparing teachers for technology use), authentic experiences (applying skills in real or simulated settings), and reflective observation (promoting internalization through peer exchange and self-analysis). Key strategies include expanding training channels, building intelligent platforms, diversifying training formats, and empowering autonomous learning.

Adequate resources, time and funding allocation for technology integration

Sustaining high-quality teacher development requires a comprehensive support system that integrates policy planning, time assurance, funding security, and talent pipeline optimization. A systematic training framework should span all career stages, combining rigorous pre-service preparation with tiered in-service programs tailored to teachers' evolving needs. Institutionalized training time enables continuous learning without disrupting teaching duties, supported by flexible formats and clear policy mandates.

Equitable and efficient funding—guided by standardized regulations and cost-sharing models—ensures accessibility across regions. Finally, dynamic talent mechanisms, including targeted recruitment, career advancement pathways, and teacher exchange programs, help build and retain a stable, competent teaching workforce essential for long-term educational transformation.

11. Ethical technology use and regulation in education

Pursuing smart education necessitates a careful balance between safeguarding personal information and enabling authorized access. Addressing the paradox of data protection and open sharing, it is crucial to ensure data security while allowing approved individuals—such as students, teachers, and educational leaders—to access necessary information. Consistently safeguarding student privacy data and using it selectively for credible purposes, such as personalized learning or research, is imperative. To achieve enhanced teaching through data interoperability, it is essential to implement seamless and secure protocols between different systems. In the realm of artificial intelligence ethics, AI tools for learning, teaching, and school management must proactively prevent potential

risks, including misuse or overuse. Ensuring algorithmic interpretability within education is paramount; this involves prioritizing reliability, control, transparency, and inclusivity. By adopting this approach, the application of intelligent technology in education remains dependable, comprehensible, and manageable.

Privacy and information security

Ensuring privacy and information security is fundamental in the digital age. Protecting sensitive data of students and educators is crucial to maintaining trust and complying with legal standards. This foundational aspect underpins all other technological initiatives in education. Robust data privacy policies and advanced security measures, such as encryption and secure access controls, are essential to prevent unauthorized access and data breaches. Continuous monitoring and regular audits of data practices further reinforce security, ensuring that personal information remains protected at all times. By prioritizing privacy and security, educational institutions can foster a safe and trustworthy learning environment.

Secure and efficient data management in education

Maintaining a secure and orderly data flow between systems is essential to safeguard data integrity and security. Effective data management ensures that information is transmitted securely and remains accurate across various platforms and applications. Implementing standardized protocols and regulatory and interoperability frameworks allows for seamless data exchange between different educational technologies, reducing the risk of data loss or corruption. Additionally, secure data flow facilitates real-time access to critical information, enabling educators to make informed decisions quickly. By ensuring that data moves smoothly and securely between systems, educational institutions can enhance operational efficiency and improve the overall quality of education.

Algorithmic interpretability in educational systems

Algorithmic interpretability in educational systems refers to the ability to understand and explain how algorithms make decisions and predictions within educational contexts. This involves ensuring that the processes and criteria used by algorithms to analyze student data, generate recommendations, and personalize learning experiences are transparent and comprehensible to educators, students, and other stakeholders.

Interpretability is crucial for building trust in educational technologies, as it allows educators to validate the fairness and accuracy of algorithmic decisions, identify potential biases, and make informed adjustments to support equitable learning outcomes. By promoting algorithmic interpretability, educational systems can enhance accountability, improve decision-making, and foster a more inclusive and effective learning environment.

Scenario-based AI ethics

Considering scenario-based AI ethics is critical for addressing the ethical implications of AI applications in education. By examining potential scenarios and their ethical impacts, educational institutions can implement AI technologies responsibly and equitably. Scenario-based ethics involves evaluating the consequences of AI deployment in various educational contexts, identifying potential risks, and developing strategies to mitigate them.

This approach ensures that AI tools are used to enhance learning outcomes while respecting students' rights and promoting fairness. By integrating ethical considerations into AI development and deployment, educational institutions can create a balanced and trustworthy digital learning ecosystem that benefits all stakeholders.

12. Prioritizing the sustainability in educational planning for the intelligent era

In advancing educational excellence in the digital age, it is essential to address several interconnected areas that collectively enhance the capabilities of educators and the learning experiences of students. These areas include establishing a consensus on a sustainable development vision, which sets the strategic direction for long-term goals. Equally important is sustainable financial planning and funding allocation to ensure that resources are directed towards high-impact areas and critical needs. Updating information infrastructure iteratively is necessary to keep pace with evolving educational requirements, while efficient digital resource aggregation and allocation maximize the use and impact of available materials. Applying innovative technologies in alignment with educational principles ensures that these tools effectively support pedagogical goals and improve educational outcomes.

Addressing these elements comprehensively will equip educators with the necessary tools and support to create a dynamic and engaging educational environment.

Education planning framework for the education 2030 agenda

Policy is a critical enabler of education digitalization, and smart education requires systematic planning to ensure the ethical and effective integration of technologies like AI. This involves balancing technological adoption with educational principles, fostering multi-stakeholder collaboration, and ensuring policies are responsive to diverse social, cultural, and economic contexts. The Education 2030 Agenda provides a global framework for sustainable education, and the proposed planning framework (illustrated in a referenced model) integrates policy vision, core themes, and implementation mechanisms to guide smart education development.

Figure 5. Smart education policy themes and framework

POLICY CONTEXTS: HISTORICAL, CULTURAL, SOCIO-ECONOMIC, POLITICAL & ENVIRONMENTAL

POLICY THEMES

DIGITAL EDUCATION RESOURCES & PLATFORMS
OER, & Open Education Practices, 4IR & AI-enabled Platforms and courseware

SKILLS & COMPETENCES
AI & 4IR -capable workforce, AI competencies for all, AI talent management, Microcredentials

CURRICULUM & PEDAGOGY
Transforming curriculum, Datafication of pedagogy & assessment; STEM Education & Smart education subjects & courseware

GOVERNANCE
AI ethics, Data Privacy, Protection & Security. Responsible AI and Digital Citizenship

INFRASTRUCTURE
Digital, 4IR & AI infrastructure to enable smart education systems, Technology framework for smart learning

MANAGEMENT & ADMINISTRATION
Education Management & Information Systems; Data driving education institutions

VISION
Leadership in a 4IR -driven, AI-driven globally competitive world based on a socially-included, humane ethical society by 2030 as per the #UN-SDGs

PRINCIPLES & VALUES
Equitable, inclusive, gender-responsive, non-discriminatory, humane, ethical, auditable

LEADERSHIP, SYSTEM CAPACITY & CHANGE MANAGEMENT
Institutional arrangements & System Capacity for Policy Implementation

PARTNERSHIPS FINANCE & RESOURCE MOBILISATION
Finance & Funding, Resource Mobilisation, Partnerships

RESEARCH, INNOVATIONS & EVALUATION
Monitoring & Evaluation, AI Research and Research Institutes

IMPLEMENTATION MECHANISMS

POLICY TRANSITIONS, TENSIONS & TRAJECTORIES

Source: UNESCO IITE, COL & BNU, 2022. Smart Education Strategies for Teaching and Learning: Critical Analytical Framework and Case Studies. Moscow: UNESCO IITE.

Iterative updates information infrastructure to meet changing educational needs

Continuously updating the information infrastructure is necessary to adapt to changing educational needs. This iterative process involves regularly assessing and upgrading technological systems to ensure they remain current, reliable, and capable of supporting modern educational demands.

It includes investments in hardware, software, and network capabilities, as well as the integration of emerging technologies. By maintaining a flexible and adaptive infrastructure, educational institutions can respond to new challenges and opportunities promptly, ensuring that students and educators have access to the best tools and resources available..

Goal-oriented digital resource aggregation

Efficient aggregation and allocation of digital resources are crucial for maximizing their use and impact. This process involves collecting a wide range of digital materials, including educational content, software applications, and data sets, and distributing them effectively across the educational system. Strategic management ensures that resources are accessible where they are needed most, enhancing the overall learning experience.

This includes creating centralized repositories that contains a number of online, offline, and hybrid degree programs offered in different countries, implementing robust resource management systems, and ensuring equitable access for all students and educators. Effective aggregation and allocation reduce redundancy, optimize resource utilization, tailor learning content and services to the loca population and support collaborative learning environments.

Technology and innovation adoption aligned with educational principles

The rise of generative AI underscores technology's revolutionary impact on education, but it also raises ethical and governance concerns. Planning must prioritize educational principles, ensuring technology enhances learning without dominating it. Key strategies include various elements from enhancing competencies to providing safe and ethical environments.

Enhancing digital competence of stakeholders

Students need digital literacy, autonomous learning, and critical thinking skills, supported by intelligent tools. Teachers require training to integrate technology, adapt roles, and leverage data-driven insights for professional growth.

Optimizing technology access mechanisms

Rigorous, differentiated access protocols ensure safe, relevant technology integration, with dynamic monitoring and ethical AI models tailored for education.

Promoting human-machine collaborative practices

Digital pedagogies and evidence-based research support effective, learner-centered collaboration, with guidelines and shared best practices enhancing implementation.

Establishing AI application standards

Technical, quality, and service standards ensure system stability, content accuracy, and ethical use, with clear guidelines for stakeholders.

Ensuring safety and ethics

Robust regulations, transparent algorithms, and user accountability prevent risks like data breaches and bias, fostering responsible technology use.

13. Effective partnerships among stakeholders in educational transformation

Intelligent technology has facilitated multi-sector collaboration within public education services, thereby expanding the scope of educational provision. Collaborative efforts between government-led entities, businesses, higher education institutions, research establishments, and other stakeholders have culminated in effective strategic partnerships. Framed as a public good, education assumes the role of disseminating knowledge and resources, collectively catering to educational institutions and educators' needs, with the overarching objective of propelling transformative technological implementations within the educational domain. It is emphasized that the application of smart technology should transcend restricted educational settings, embracing broader societal contexts.

Adaptive breakthroughs in overcoming education reform barriers

Education reform is a dynamic process shaped by evolving societal needs, technological progress, and cultural shifts. While often met with challenges and resistance, not all barriers are negative—many reflect diverse perspectives essential to meaningful change.

Resistance can reveal overlooked issues and offer pathways to more inclusive, resilient reforms. Rather than avoiding these obstacles, reform efforts should view them as opportunities for strategic adaptation. Key barriers typically arise from perceptual biases and a lack of collaborative synergy, both of which—if addressed—can catalyze deeper, more effective transformation.

Perceptual Biases Hindering Education Reform

Simple fragmented solutions weaken reform by addressing surface problems without tackling

deeper systemic issues. While digital technologies offer opportunities for learner-centered transformation, many reforms remain fragmented—adding tools or resources without structural change. This leads to policy overload, resource waste, and limited impact. In the digital era, such approaches often result in superficial tech adoption without pedagogical integration. Effective reform requires a shift to system-driven strategies that use technology to reimagine and restructure education holistically.

Insufficient collaborative synergies weakening reform outcomes

Digital transformation is a complex, systemic process that reshapes education through sustained integration of digital, networked, and intelligent technologies. This transformation requires collaboration not only within education systems—across departments like teaching, training, research, and technology—but also with external stakeholders, including government, technology enterprises, and higher education institutions. However, the structural tension between the holistic, collaborative demands of digital transformation and the traditional hierarchical, siloed nature of education systems creates significant barriers. These manifest as incomplete cross-departmental mechanisms, weak regional coordination, and limited information sharing, all of which undermine reform outcomes.

Key elements of digital cross-sectoral collaboration

Digital technology has transformed governance, shifting from hierarchical "command-control" systems to flatter, networked, and intelligent models. Technology enhances communication, reduces information asymmetries, and fosters multi-stakeholder decision-making and optimization. However, its effectiveness depends on integrating technological advancements with institutional innovation, ensuring clear operational

However, its effectiveness depends on integrating technological advancements with institutional innovation, ensuring clear operational logic and sustainable pathways. Key elements include value consensus, equitable interest distribution, and shared cost allocation, supported by structured mechanisms to align roles and processes.

Value consensus

Value consensus is the foundation of educational reform, aligning stakeholders on shared goals and principles. Despite varying political, economic, and social contexts, education reform globally aims to adapt to societal changes and meet talent demands. This consensus transcends system optimization, focusing on fostering peace, justice, and sustainability. The 2022 UN Transforming Education Summit highlighted education as a human right and a driver of socioeconomic development, necessitating deep transformation to address crises like inequality and regional disparities. The summit's Vision Statement on Public Digital Learning identified content, capacity, and connectivity as key pillars, urging stakeholders to ensure accessible, high-quality digital learning and transform ecosystems to meet digital-era demands.

Interest distribution

Education reform, as a resource-intensive endeavor, requires careful interest coordination among government, schools, parents, organizations, and enterprises. Challenges include power struggles and inadequate incentive mechanisms, which can lead to passive collaboration or misalignment with public interests. Effective mechanisms—decision-making, responsibility delineation, information sharing, constraints, flexible services, differentiated incentives, performance linkage, and oversight—ensure stable, equitable collaboration. These mechanisms balance diverse interests, prioritize

fairness for disadvantaged groups, and account for temporal shifts in stakeholder perceptions, fostering long-term stability through continuous evaluation and feedback.

Cost sharing

Collaboration involves significant costs such as search, negotiation, contracting, and execution, spanning time and resources. Transparent, sustainable cost-sharing mechanisms, guided by the principle of "beneficiaries bear costs," clarify responsibilities across government, institutions, and enterprises. Costs include preparatory efforts, trust-building negotiations, formal agreements, and implementation oversight, requiring clear delineations to ensure fairness and sustainability..

Part IV

Landscape of smart education for the futures of education

Box 4.

Smart education, as a paradigm for the intelligent era, aligns with the global vision for education by 2050, bridging technological innovation with human-centered values, and advancing both strategic intent and practical pathways to reimagine educational ecosystems. Positioned at the intersection of possibility and purpose, smart education offers structural potential to address some of the most persistent challenges in education today. Among them is the long-standing "Educational Trinity" —the tension between achieving high-quality, large-scale, and personalized learning. High-quality education is often tied to individualized instruction and small class sizes, which limit scale. Large-scale systems can offer broad access, but frequently at the expense of personalization. Meanwhile, personalized learning—despite its promise—often encounters prohibitive resource demands that hinder scalability. Smart education transcends the notion of technology as a mere tool; it presents a systemic vision for transforming teaching, learning, and governance alike. This section explores possible future scenarios of education in the age of intelligence, emphasizing smart education's pivotal role in building more equitable, resilient, and future-ready learning systems across the globe.

14. Global concept and national strategy on smart education

The smart education public service system is central to educational equity and quality. It drives governance innovation and supports an inclusive digital society through data-enabled transformation. Nationally, platforms like China's National Smart Education Platform enhance functionality, resource access, and service quality, supporting remote learning and teaching improvements. Regionally, integrating digital institutions, optimizing resource exchange, and leveraging smart technologies for safety and decision-making enhance efficiency and inclusivity. The system also promotes lifelong learning through diverse, high-quality digital resources, platforms, and technical support, fostering a learning-oriented nation.

Public service architecture for smart education

The national public service system (See Figure 6 below) provides plans for functionality, structure, and data centers, promoting scale and personalization to advance the UN's 2030 Agenda. It comprises four layers: Technology-enabled learning and teaching ensure scalable, personalized education through equitable resource access, continuous improvement, and multi-sectoral collaboration.

Technology-enabled learning and teaching ensure scalable, personalized education through equitable resource access, continuous improvement, and multi-sectoral collaboration.

Service forms include infrastructure, resource development, teaching support, career planning, information management, and teacher development, offering resource supply, professional development, cross-domain sharing, and collaborative innovation.

Figure 6. Public service architecture for smart education

Technology Empowers Learning and Teaching	**Large-scale education and Personalized learning** Learners need high-quality learning services to meet their development anytime and anywhere.		
	Inclusion and Equity	Continuous Improvement Culture	Multi-Sector Cooperation and Partnerships

Service Form	Information Infrastructure	Digital Education Resources	Learning and Teaching Support
	Career Planning and Employment	Education Information Management	Teacher Professional Development

Diversity Service Provision	Initiator	Sponsor	Developer	Operator	Evaluator	Supervisor

Education Governance and Policy Program	**Policy, Governance, Fund, and Resources** National public services for Smart Education interaction between economy, system, culture, technology, research and innovation.

Source: Huang, R. H., et al. 2022. Rethinking and Redesigning National Smart Education Strategy. Beijing: Beijing Normal University.

Diversity Service Provision involves initiators, sponsors, developers, operators, evaluators, and supervisors, ensuring comprehensive, sustainable service delivery.

Education Governance and policy program ensure ethical technology integration and efficient, modernized governance through legal and policy frameworks.

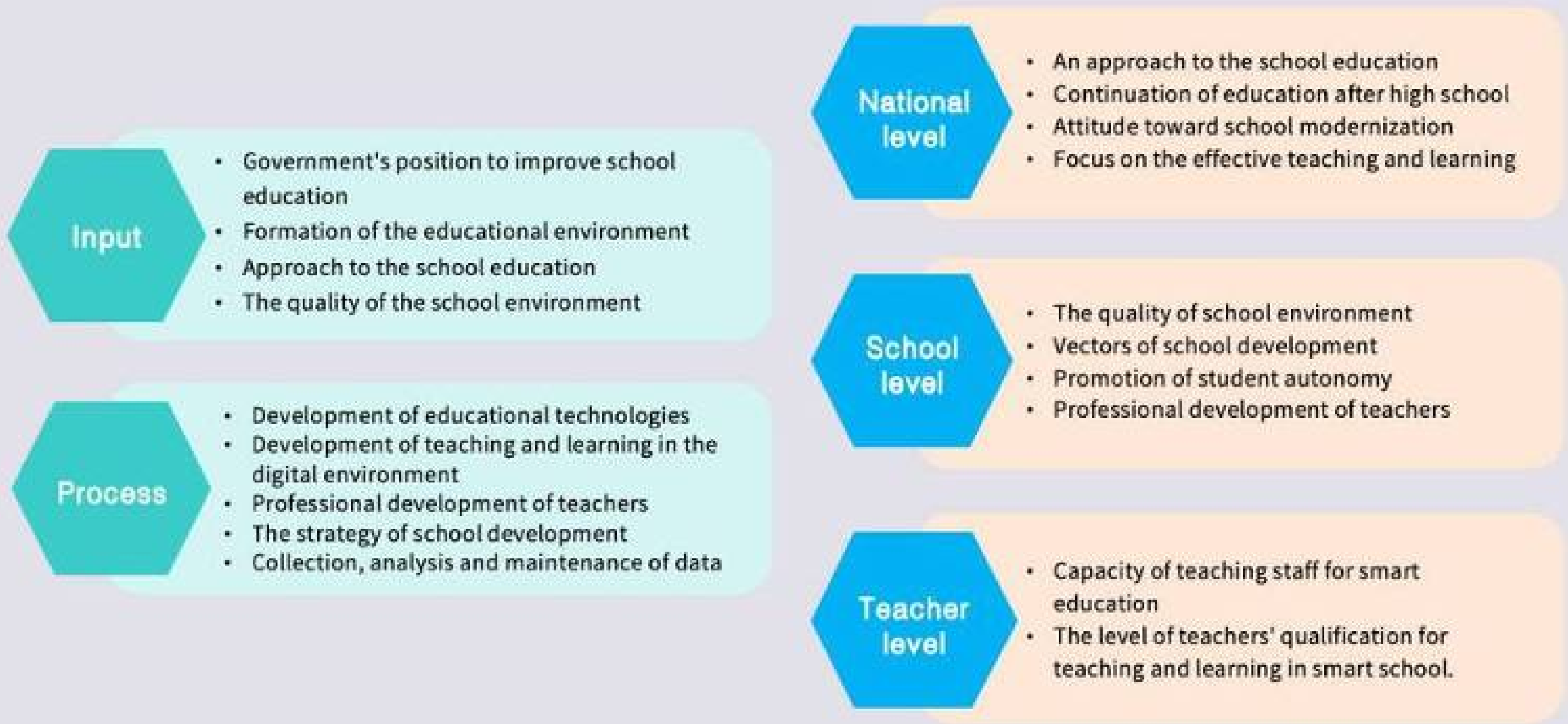## International assessment and monitoring of smart education

Education quality, inherently complex and dynamic, requires long-term, scientific monitoring to ensure fair, accurate assessments. Monitoring uses comprehensive data to evaluate quality, guide improvements, and support high-quality development. National education systems, interconnected and interdependent, rely on systematic monitoring to reflect quality, identify issues, and optimize resources, particularly in

digital transformation contexts where smart education is a modernization priority.

The national monitoring framework (Figure 7) assesses smart education conditions, providing structured indicators across input, process, and outcome dimensions at national, school, and teacher levels. Inputs evaluate policies, funding, and infrastructure; processes assess teaching, learning, and management changes; outcomes measure transformation impacts.

Data sources include international datasets, national statistics, and school-level data, ensuring comprehensive, reliable insights. National-level indicators focus on strategic implementation and resource allocation, school-level indicators on environmental quality and digital teaching, and teacher-level indicators on digital competencies, driving evidence-based decisions and policy optimization.

Figure 7. National smart education monitoring framework

Input
- Government's position to improve school education
- Formation of the educational environment
- Approach to the school education
- The quality of the school environment

Process
- Development of educational technologies
- Development of teaching and learning in the digital environment
- Professional development of teachers
- The strategy of school development
- Collection, analysis and maintenance of data

National level
- An approach to the school education
- Continuation of education after high school
- Attitude toward school modernization
- Focus on the effective teaching and learning

School level
- The quality of school environment
- Vectors of school development
- Promotion of student autonomy
- Professional development of teachers

Teacher level
- Capacity of teaching staff for smart education
- The level of teachers' qualification for teaching and learning in smart school.

Source: Huang, R. H., et al. 2022. Rethinking and Redesigning National Smart Education Strategy. Beijing: Beijing Normal University.

Global Smart Education Development Indicators

Global experts wrote the 2024 report International Understanding of Smart Education under Digital Transformation to show how smart education improves quality, supports fairness, and helps transform education. Integrating UNESCO, World Bank, PISA, TALIS, and NRI data, it constructs a framework with 10 primary and 30 secondary indicators (Table 1), assessing performative (PF) and constructive (CF) features.

PF indicators include student-centered teaching (PF1), comprehensive assessments (PF2), ubiquitous learning environments (PF3), continuous improvement culture (PF4), and inclusivity (PF5). CF indicators cover student community building (CF1), ethical technology use (CF2), teacher development (CF3), sustainable planning (CF4), and cross-sectoral collaboration (CF5).

Analysis of 81 countries reveals varied performance. Ethical technology use (CF2) and inclusivity (PF5) score highly, reflecting global emphasis on responsible technology and equity. However, sustainable planning (CF4) and continuous improvement culture (PF4) score lower, indicating challenges in long-term policy stability and cultural consensus.

High-income countries excel in ethics and inclusivity due to robust regulations, while middle-income countries prioritize teacher development and assessments. Low-income countries struggle with sustainable planning and collaboration due to limited resources and weak governance, hindering systematic implementation.

Table 1. Key indicators of smart education at the national level

Smart Education Features	Primary Indicators	Secondary Indicators
Performance Features (PF)	PF1 Student-Centered Teaching	1.1 Application of digital technologies in teaching 1.2 Active learning and creativity cultivation 1.3 Student agency and autonomy
	PF2 Holistic Learning Assessment	2.1 Comprehensive teaching and learning evaluation 2.2 Diverse teacher-student feedback mechanisms
	PF3 Smart Learning Environment	3.1 Seamless high-quality network connectivity 3.2 Personalized digital learning resources 3.3 Reliable educational digital infrastructure
	PF4 School Organizational Leadership	4.1 Digital leadership and evidence-based decision making 4.2 Teacher collaboration and communication 4.3 School's forward-looking considerations
	PF5 Educational Equity	5.1 Resources and facilities for special needs students 5.2 Gender equality in education 5.3 School inclusion and equity 5.4 Equitable distribution of educational resources
Constructive Features (CF)	CF1 School Cultural Development	1.1 Cultural diversity building in schools 1.2 Students' social-emotional skills 1.3 Students' digital literacy
	CF2 Data Security and Governance	2.1 Protection of teacher and student data privacy 2.2 Technology regulation and legal frameworks
	CF3 Teacher Capacity Building	3.1 Teacher professional development 3.2 Pre-service teachers' digital competence 3.3 In-service teachers' digital competence
	CF4 Sustainable Education Reform	4.1 Long-term investment in educational infrastructure 4.2 Digital resource integration 4.3 Educational innovation and technology adoption 4.4 Education funding and investment
	CF5 Cross-Sector Collaboration	5.1 Public participation in decision-making 5.2 Accessibility of government online services 5.3 Government data publication and utilization

15. Social experiments and governance on education transformation with generative AI

As a new paradigm, intelligent governance offers data-informed, adaptive approaches to drive systemic reform. Yet this transformation brings challenges—ethical risks, data security, inequality, AI interpretability, and policy complexity—all of which demand careful balancing between innovation and accountability. Educational social experiments provide a powerful method for evaluating AI's impact, guiding reform, and developing evidence-based policies, it offers theoretical and practical pathways for long-term, system-level educational transformation.

Integration degree of AI in education

The integration degree of AI in education measures how well technology aligns with educational needs, reflecting the interplay between educational logic and technical capabilities. It encompasses AI's tool attributes and its interaction with teaching content, methods, and environments, requiring a dynamic balance to optimize fit. Implicitly, integration is gauged by adaptability, effectiveness, and sustainability, measured through indicators like teaching efficiency, student experience, and equity support. Explicitly, it is reflected in behaviors like misuse, avoidance, or overuse.

Misuse of technology

Misuse occurs when AI applications violate ethical norms or educational principles, leading to functional distortion. Schools deploying surveillance tools (e.g., eye-tracking, facial recognition) risk privacy violations and trust erosion, potentially harming student development. Teachers using AI for rote learning neglect critical thinking and personalization, causing "intelligent degradation." Students misusing AI for content copying or cheating weaken autonomy, foster laziness, and risk academic misconduct. Issues like gaming addiction and cyberbullying further threaten mental health and behavior.

Avoidance of technology

Avoidance stems from cognitive limitations, fear of uncertainty, or inadequate infrastructure and skills. Schools face funding shortages, talent deficits, or outdated systems, limiting AI adoption. Teachers resist due to technical barriers or "AI anxiety," lacking training or clear application methods. Parents, fearing health or addiction risks, restrict children's AI exposure, limiting learning opportunities.

Overuse of technology

Overuse involves blindly applying AI without considering educational needs, ignoring appropriateness. Schools pursue superficial smart campus initiatives, wasting resources and neglecting core issues. Teachers over-rely on AI data, diminishing emotional engagement and teaching quality. Students face information overload from algorithmic recommendations, risking addiction, "filter bubbles," and mental health issues like depression or attention deficits.

Trustworthy AI in education

The rapid advancement of AI and emerging technologies is driving a comprehensive societal transformation, impacting economic behaviors, industrial structures, social frameworks, ethical norms, and daily life. In education, AI demonstrates immense potential, but its integration raises concerns about widening educational divides, privacy breaches, and algorithmic biases. Global digital education efforts aim for equitable, sustainable reform to bridge divides and promote inclusivity. In China, policies like the Next Generation AI Development Plan emphasize robust AI laws, ethics, and policies. The 20th National Congress Report underscores building a high-quality education system, advancing digitalization, and fostering a learning-oriented society. The Education Powerhouse Construction Plan (2024–2035) promotes AI-driven educational reform. Amid challenges from generative AI and large-scale

models, trustworthy AI—reliable systems, products, and services—has become a global consensus and governance priority. In education, trustworthy AI addresses digital transformation, focusing on student development, teacher growth, and learning environment upgrades. It analyzes AI's potential and challenges, proposing trustworthiness criteria and an evolutionary model (Figure 8) to guide effective governance and ensure healthy digital education development. Ethical concerns—such as algorithm-driven filter bubbles (which limit exposure to diverse ideas), short-video addiction, and over-reliance on AI for problem-solving—highlight the need for careful and value-driven integration of AI in education, assessed in terms of its demand, potential, and challenges.

Figure 8. Evolution model of trustworthy AI in education
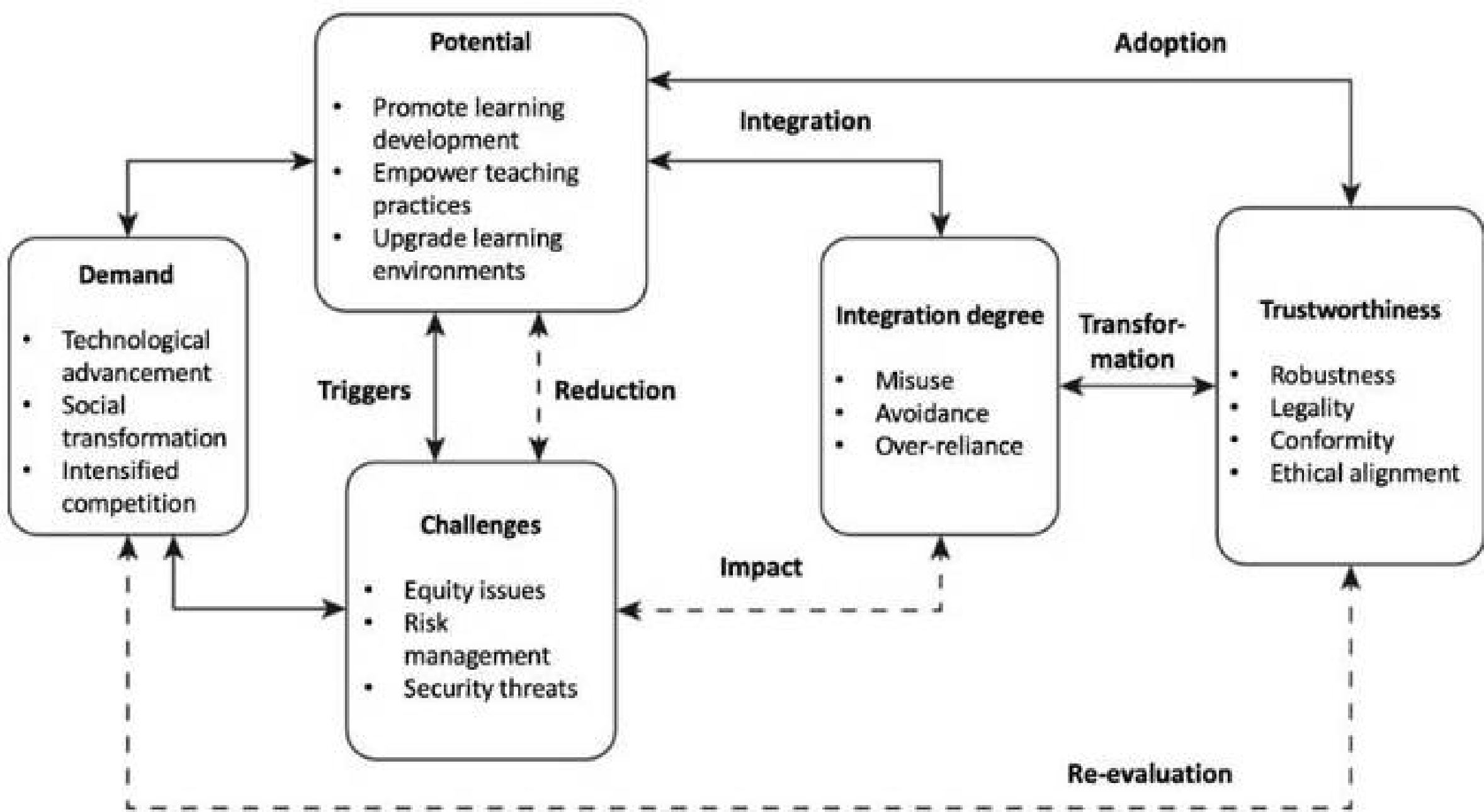
Source: Huang, R. H. (2022). On the systemic integration of technology and education. *Chinese Journal of Distance Education*, (7), 4–12, 78.

Educational social experiments in the intelligent era

Artificial intelligence (AI) is continuously expanding the functional boundaries of education systems. It enables personalized, contextualized, and data-driven learning; transforms learning environments into intelligent and adaptive spaces; diversifies modes of content delivery; and supports more proactive teaching strategies. In this process, key stakeholders—including students, teachers, and administrators—are empowered by real-time data insights to make more informed decisions.

As education systems undergo increasingly complex structural transformations, traditional research methods—often reliant on small samples and controlled environments—have become insufficient for analyzing large-scale and dynamic reforms. There is an urgent need for innovative research paradigms capable of addressing the systemic challenges brought about by the digital and intelligent transformation of education.

Aligned with this background, educational social experiments have emerged as a critical methodological approach for understanding the systemic impact of AI in education. These

experiments integrate interdisciplinary resources—linking technology, education, and the social sciences—to build evidence-based research frameworks that promote the normative and sustainable application of AI. Enabled by big data, supercomputing, and other emerging technologies, educational social experiments offer scalable and multimodal research capabilities that allow for in-depth exploration of complex variables and systemic interactions within educational reform. Figure 9 shows a framework for research on educational social experiments.

The methodological framework of educational social experiments consists of two major components, research procedures and dimensions for analyzing social activities.

Four core research procedures, which structure the experimental process:

Evidence-based methods: Techniques used to identify and examine the existence of specific phenomena in educational settings, including problem definition, phenomenon observation, and pattern exploration;

Evidence representation: Criteria for evaluating whether the phenomenon exists, such as the duration of observation, sample size, and types of data or cases collected;

Contextual analysis: Interpretation of the background and situational conditions of the activity under investigation, providing a structured understanding of the phenomenon's context;

Expression and communication: The structured presentation of research objectives, questions, methods, procedures, and findings, aimed at ensuring clarity and accessibility for diverse audiences.

Four key dimensions for analyzing social activities, which characterize the experimental subject:

Input variables: Refers to the information and resources related to the phenomenon under examination, including human, financial, and temporal investments that support the activity's operation.

Intervention Agent: The key agents or entities that drive the occurrence of the phenomenon, such as individuals, institutions, technologies, or forms of authority, responsible for initiating, sustaining, and shaping the activity.

Figure 9. Framework for research on educational social experiments
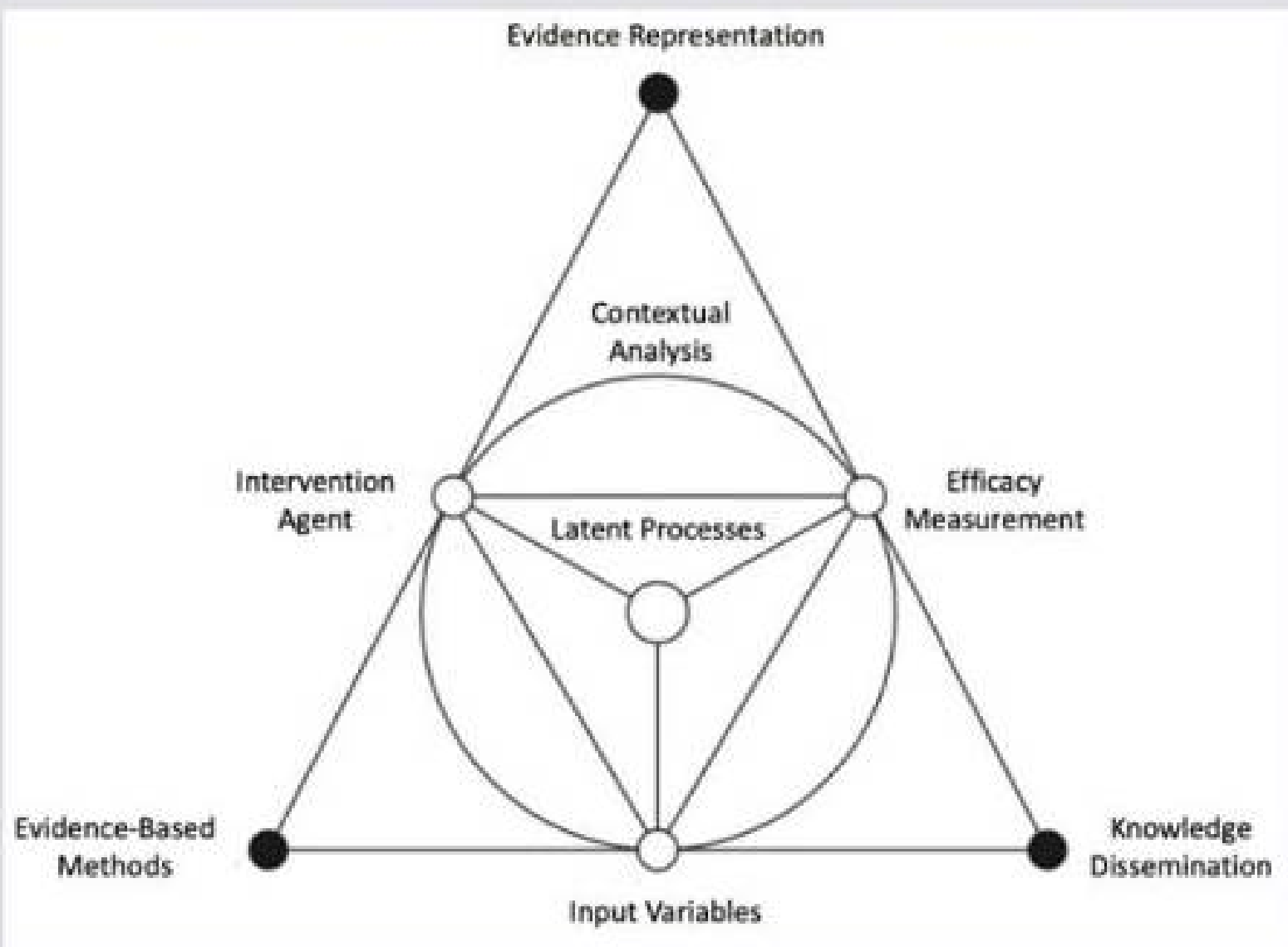
Source: Huang, R. H., Wang, H. H., Zhang, M. H., Lu, X., Wang, Y., Gao, B. J., & Du, J. (2020). Educational social experiment research for the intelligent era. *E-Education Research*, 41(10), 5–14.

Efficacy Measurement: The observable outcomes or changes associated with the activity, which serve as indicators of its impact and influence.

Latent Processes: The flows of data, information, and resources within the activity, with particular attention to how these elements circulate and interact throughout the system.

Together, these methodological components provide a comprehensive framework for examining educational innovation in the age of intelligence. Educational social experiments offer both theoretical guidance and practical tools for assessing systemic change and informing evidence-based policy and institutional decision-making.

16. Global ecosystem of smart education with integration of intelligent technology

In the intelligent era, education urgently requires deep integration of intelligent technologies, a critical measure for innovation and high-quality development. Historically, science-education integration focused on using technology to optimize teaching processes, content, tools, and school management. As global digitalization advances, technology's potential to enhance student growth, teacher development, and learning environments has gained international recognition.

Spiral integration of technology and education

The dynamic interplay of technological progress, societal transformation, and educational change drives a comprehensive, systemic integration across all domains, elements, chains, and operations, characterized by broad scope, diverse methods and rich value.

Figure 10. A spiral development of education empowered by intelligent technology
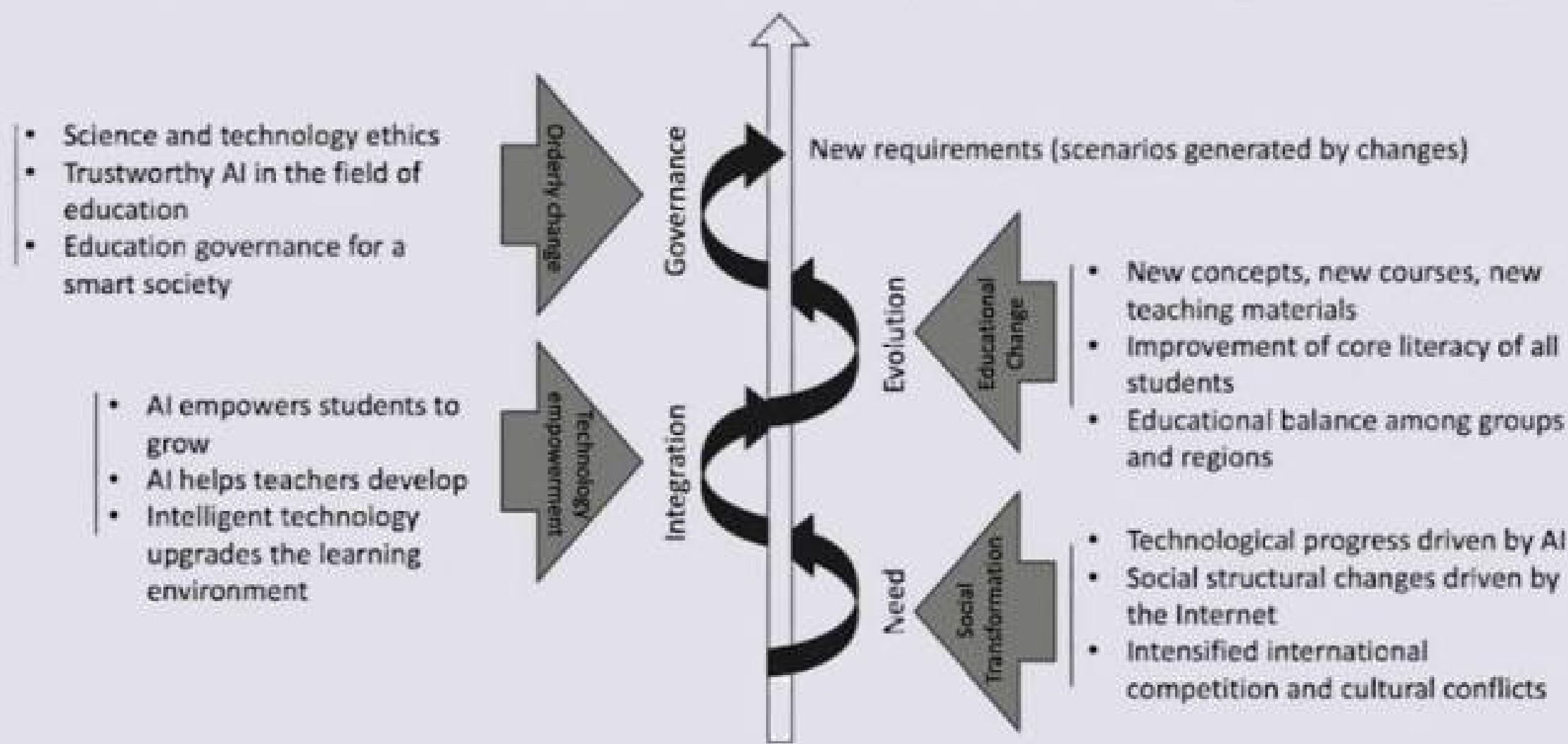
First, identifying transformative scenarios in societal transformation is key to defining new educational demands. Second, the new technological revolution, with AI as a core driver, underscores technology's role in education. Third, education's complexity and variability necessitate change simulations to manifest technological value. Fourth, improper use of intelligent technologies poses ethical, privacy, and security risks, requiring effective governance to ensure orderly reform.

Promoting the integration of science and education through diversified learning scenarios

The rapid advancement of AI, the internet, and big data demands high-caliber innovative talent, while China's educational reform needs address new demands. Three key concerns include: shifting educational philosophies to enhance digital thinking, recognizing the lack of evidence-based research and social experiments in technological transformation, and addressing underdeveloped intelligent evaluation mechanisms. Advancing science-education integration through diverse scenario transformations leverages technology, resources, and innovative models to enhance quality, equity, and talent cultivation.

Prioritizing and defining transformative scenarios

Scenarios describe unified constructs of time, space, actors, and events. Challenges include vague scenarios due to misaligned external technological drivers and internal reform motivations, and generalized scenarios from "double black boxes" —technological and applicative ambiguities. Defining scenarios based on real needs in teaching, learning, assessment, evaluation, and management, prioritized by urgency, drives systemic change.

Phased implementation of teaching reform

Education informatization has demonstrated technology's value, but cognitive biases often overestimate short-term impacts and underestimate long-term effects. Blind adoption of costly technologies risks low returns, hindering digital transformation. Phased, flexible reforms based on digital maturity, stakeholder readiness, and resource availability, guided by demand-driven principles, ensure sustainable progress.

Simulating and representing the change process

Traditional research struggles to elucidate deep reform mechanisms, often criticized for lacking practicality. Diverse evidence-based, data-intensive, and intelligent computing approaches reveal structural causes and implicit patterns. Social experiments analyze large-scale, long-term data to uncover hidden processes and propose interventions, while digital twin simulations visualize multi-variable interactions, guiding real-system optimization.

Strengthening technical governance with ethical principles

Ethical concerns, such as algorithmic biases, addiction, and reduced cognitive effort, highlight the need for governance. Effective governance ensures normative, ethical, legal, and robust technology integration, while leveraging technologies for precise, efficient governance, modernizing systems and capabilities.

Typical scenarios of science-education integration under educational transformation goals

China's educational digital transformation drives systemic change across all elements, operations, domains, and processes, aiming to foster digital awareness, enhance stakeholder capabilities, shift paradigms to intelligent models, and build open, efficient smart education ecosystems with adaptive governance. Stability, forward-looking models, innovative teaching, and robust governance are critical. Deepening transformation promotes integration, expanding collaborative innovation and fostering diverse scenarios to support high-quality development.

Empowering education system to proactively adapt to the pace of technological change

New technologies penetrate all societal facets, outpacing adaptation capacities and challenging education. Education must shift from reactive to proactive, embracing systemic reforms in philosophy, systems, and research paradigms. Robust strategic planning, trend analysis, intelligent platforms, technological breakthroughs, risk monitoring, and governance mechanisms ensure a resilient, adaptive, innovative ecosystem.

Developing students' vital competences in the intelligent era

AI reshapes educational models, supporting personalized learning, teacher development, environment upgrades, and research innovation, cultivating citizens with key competencies: lifelong autonomous learning, innovative AI application, flexible employment adaptability, uncertainty handling, and thriving in intelligent environments. These ensure students meet diverse future challenges.

Improving teachers' capability of teaching with human-machine collaboration

Teachers transition from knowledge transmitters to mentors fostering character, critical thinking, and problem-solving. AI handles repetitive tasks, freeing teachers for high-order guidance, while collaborative models like dual-teacher systems and digital twin interactions enhance precision and engagement, optimizing knowledge construction.

Enhancing the capacity for technological governance and regulation in cyberspace

A robust cyberspace governance system is vital for education transformation. This involves intrinsic data security across product lifecycles, enhanced legal frameworks addressing education's complexity, and multi-stakeholder collaborative mechanisms. Privacy computing, regulatory enforcement, and ethical oversight ensure a secure, efficient smart education ecosystem, supporting high-quality digital transformation.

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China's actions in developing smart education

Amid the global acceleration of educational digital transformation, China has actively responded to the emerging challenges and opportunities of the intelligent era. Since 2022, the Chinese Ministry of Education has launched two flagship initiatives—National Education Digitalization Strategy Action Plan and National Smart Education Platform—to drive nationwide transformation. Building on these efforts, the Ministry released the White Paper on China's Smart Education at the 2025 World Digital Education Conference, offering a comprehensive account of China's strategic vision, implementation pathways, and practical achievements in advancing digitalization and developing smart education. In the same year, the China National Academy of Educational Sciences published the Global Digital Education Development Index, which based on a multi-modal analysis of evidence, reflecting steady worldwide progress. These developments form part of a broader, evolving landscape in which the theoretical foundations and systemic logic of smart education continue to be refined—an exploration to which the present volume seeks to contribute.

Smart education

Pathways toward education 2050

At the historical juncture of "the Inaugural Year of Smart Education", the educational digital transformation is advancing toward a critical breakthrough. Looking ahead to the future of education in 2050, this book positions smart education as a transformative response to the evolving demands of the intelligent era. While rooted in the principles of the Education 2030 Agenda, particularly the recognition of education as a global common good, this vision extends further, anchoring itself in the long-term horizon of 2050. It seeks to promote inclusive development, social equity, and sustainability in an increasingly digital and interconnected world. Build on this value, smart education emphasizes high-quality learning, flexible and adaptive content, and enhanced instructional efficiency.

This book centers on smart education, offering a systematic and forward-looking exploration across four dimensions: from digital transformation to smart educaiton, the performative features of smart education as a shared vision, the constructive features of smart education in sustainable ways, and landscape of smart education for the futures of education. It aims to build a panoramic conceptual framework and explore innovative pathways for educational transformation in the age of intelligence.

Ultimately, the book aims to offer both theoretical foundations and practical insights to support educational transformation in the intelligent era—contributing to global conversations on future-ready education systems and inclusive innovation.