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Strategic framework and global trends of national smart education policies

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Integrating intelligent technology to promote smart education, had become a focus of education policies in many countries. However, there was little literature on strategies and trends of smart education policies at the national level. This study investigated the framework for developing national smart education strategies and trends of national policy making on smart education. Based on the Delphi technique method, a National Smart Education Framework was developed, consisting of four essential leveraging points: (1) forward-thinking governance and policy initiatives, (2) digital learning environments conducive to smart education, (3) transformative teaching and learning enabled through technology, and (4) overarching considerations. Additionally, a textual analysis method was employed to analyze 24 smart education policies from 24 countries or organizations, to uncover the strategies and policy trends of smart education in accordance with the proposed smart education framework. Promoting high-quality, inclusive, and accessible education, increasing Internet connectivity and access to digital tools, enhancing digital skills, ensuring information security and privacy, implementing new digital pedagogies, providing real-time feedback, emphasizing critical thinking, problem-solving, and creativity, etc. were the main trends for smart education policy making. The findings of this study provide valuable insights for policymakers and educators in shaping smart education policies and practices worldwide to promote sustainable development.

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Introduction

In the intelligent era, technologies can be a catalytic component of digital transformation in education. In the 2022 Transforming Education Summit, the United Nations Secretary-General António Guterres pointed out that education is in crisis and the education system accumulated many problems, including only focusing on scores, neglecting lifelong learning, insufficient teacher training, the digital divide, the education funding gap, etc., which profoundly affected social, economic, political, and cultural development in the 21st century (United Nations 2022). The infusion of intelligence technologies in education has the potential to increase the resilience of education and implement high quality education if necessary (Naidu 2021; Román et al. 2021). Developing and implementing rewarding smart education strategies and solutions can expand access to quality education and lifelong learning opportunities to promote the realization of Sustainable Development Goal 4 (UNESCO IITE 2022). Although the adoption of intelligence technologies to improve the education system was widely advocated (Gulson and Witzenberger 2022), it was frequently criticized for lacking a theoretical basis (Singh and Miah 2020). Furthermore, many countries gradually adopted smart education as a critical policy theme for integrating ICT in education and promoting the digital transformation of education (Chatterjee et al. 2020). The integration of intelligent technology in education has made smart education a major theme in many countries' educational policies. However, there is little literature on how to plan smart education at the national level. To address this gap, this study aims to answer the following research questions: (1) How can smart education be constructed at the national level? (2) What are the global policy trends of smart education? The paper is structured as follows: the development stages of smart education are presented in the second section, the research methodology is presented in the third section, a National Smart Education Framework for policy making is proposed in the fourth section, and the strategies and trends of national smart education policies are analyzed in the fifth section. The paper concludes with a summary of the findings.

Four development stages of smart education

Overall, smart education included four development stages: (1) the emerging of smart education from 1983 to 2007; (2) the evolving of smart education from 2008 to 2012; (3) the theorizing of smart education from 2012 to 2018; (4) the application of smart education from 2019 till now.

Stage 1: The emerging of smart education. In the first stage, from 1983 to 2005, the term "smart education" started to be used, however, "smart" mainly referred to the cultivation of human wisdom. Fedoretz (1983) used the term "wisdom education" in the paper *Educate People with Wisdom: Pieces of Childhood Memoirs*, which first explored how to cultivate talents with wisdom. In the 1990s, Qian proposed the *Theory of Metal Synthetic Wisdom* to guide people to acquire wisdom and creativity as soon as possible. This view held that wisdom was the unity of wisdom and cognition (Qian 2011). In 1997, Malaysia carried out the *Malaysian Smart School Implementation Plan*. In 2003, Smart Education was discussed in the field of earth and space science, but Thomas V thought that Smart referred to Science, Mathematics, Aerospace, Research, and Technology (S.M.A.R.T.) (Thomas and Carruthers 2003). What's more, cultivating smart and creative talents was the hot top and important task of education. Chen and Tang (2000) believed that smart education referred to learning knowledge from one example and inspiring students' hearts and wisdom, that is, an educational model that attached equal importance to learning and thinking and took the improvement of teaching quality as its main purpose. Jing (2003) believed that the pursuit of wisdom development was a value orientation of contemporary educational reform.

Stage 2: The evolving of smart education. In the second stage, from 2006 to 2011, the term "smart education" was mainly used to refer to integrating technologies in education. In 2006, the Singapore government announced the *Intelligent Nation 2015*, which aimed to build Singapore into a smart country and a globalized city by using ubiquitous information and communication technologies. In 2008 and 2009, IBM first proposed the concept of "Smarter Planet", which extended to smarter education, smarter city, smarter work, smarter transit, etc. This view was closely related to the rapid development of technologies. Here, the word "smart" mean automation (Palmisano 2008). The support of ubiquitous technology caused further changes by moving learning styles away from mobile learning toward ubiquitous learning, which emphasized that learning could take place anytime and anywhere without the limitations of time, location, or environment (Hwang et al. 2008). Vlad et al. (2011) mentioned that notebooks can be used to build an electronic platform to help students learn better and achieve smart education. The government's policies started to attach great importance to smart education. For example, South Korea issued the national education policy of *Adapting Education to the Information Age in 2011*, which stated that SMART Education represented for self-directed, motivated, adaptive, resource-enriched, and technology-embedded education. The policy initiated to use ICT was a primary source of learning to tailored to the needs of each individual student. However, in this period, smart education did not attract widespread attention among educational policymakers around the world.

Stage 3: The theorizing of smart education. In the third stage, from 2012 to 2018, with the development and application of intelligence technologies, such as the Internet, Internet of Things, cloud computing, big data, blockchain, and artificial intelligence, the research of smart education increased by years, which deepened the theoretical understanding of smart education. Zhu and He (2012) believed that smart education was a new frontier of ICT in education and advocated that a smart learning environment with perception, reasoning, and decision-making should be created to promote comprehensive, coordinated, and sustainable development in smart education. Kim et al. (2012) considered that smart education was proposed for several reasons: first, it focused more on people and content than on devices; second, it was effective, intelligent and customized learning based on advanced information technology infrastructure. According to Huang (2014), smart education can be defined as the educational behaviors (system) provided by schools, regions, or governments with the characteristics of the high learning experience, learning content adaptation, and teaching efficiency. Middleton (2015) also specified the learner-centered aspects of smart learning and how it benefits from the use of smart technologies. Personalization and smart technologies engaged learners in their learning and increase their independence in a more open, connected, and enhanced way through richer personal environments. This provided implications for future research related to smart education applications. In this period, it was generally becoming common sense that smart education could be viewed as utilizing modern science and technologies to provide personalized and diversified supports and services for students, teachers, and parents, etc. The teaching and learning process data were recorded and used to promote the quality and equity of education.

Stage 4: The application of smart education. In the fourth stage, from 2019 until now, smart education was taken as the main theme of educational policies in different countries, and several documents related to smart education were released by UNESCO. The Ministry of Education (MOE) of China issued the *Action Plan for ICT in Education 2.0* in 2018 and issued the policy on the *Construction Project of "Smart Education Pilot Zones"* in 2019, which emphasized digital literacy, innovative teaching methods and strategies, precise assessment of the students' comprehensive quality evaluation, personalized and on-demand service, open educational resources and the new mode of educational governance. Smart Education appeared in the planning documents at the national level to promote educational equity and improve educational quality. The *Green Smart Future School* issued by the South Korean government in 2022 mentioned that Korea selected 702 buildings (484 schools) in large-scale planning to build the Green Smart Future School, equip these with digital infrastructure, and create an advanced intelligent teaching environment. In 2022, UNESCO IITE proposed a critical analytical framework for smart education and developed indicators to monitor and evaluate the status of smart education. Smart education was no longer an afterthought during this period, but rather a large-scale practice and action. Yang et al. (2021) proposed a smart education framework for the 5 G era based on intelligent technology, typical applications, learning and teaching reform, and the new smart education ecology. Many scholars designed or proposed a systematic framework related to smart education, the perfect framework was very important for teaching practice, and a smart education framework would guide the design of future smart education systems (Demir 2021). Some researchers designed and developed solutions for smart education. For example, Zheng et al. (2023) used evolutionary algorithms and machine learning algorithms to build a big data platform for smart education and better assist the establishment of a smart education system. Badshah et al. (2023) formulated a solution for the Internet of Things to move towards smart education, including smart pedagogy, smart assessment, smart classroom, and smart management. Luo and Yang (2024) discussed various applications of the large language model and domain-specific model collaboration for smart education, including group learning, personalized tutoring, classroom management, etc. A well-developed framework for smart education also optimized the process of managing the human, economic and technological resources of educational institutions and research centers. Even though researchers presented various frameworks for smart education, no national level policy framework for large-scale application was proposed.

Method

Delphi method for the framework. The Delphi method is a commonly used research technique in social science to gain consensus on complex issues from a group of experts. In this study, the Delphi method was used to validate the preliminary constructed national smart education framework. To begin, experts were selected from UNESCO, China, and the U.S. total of 14 experts were included in the study (see Table 1). The study participants were all professionals working in the field of educational technology or digital education. All participants agreed to participate in the process.

In the preparatory phase, based on the literature review, we proposed a draft of the National Smart Education Framework. Then, we started to validate the framework which was described as follows: Step 1 was an introduction and explanation of the proposed framework through emails and collected feedback from experts. In Stage 2, based on the feedback, the framework was edited, and experts talked their views on the dimensions of the National Smart Education Framework via videoconferencing systems, and the framework was revised again. In Stage 3, the experts were asked to evaluate the revised framework via emails and provide feedback until a consensus was reached.

Table 1 Experts demographic profile.

Expert category		Workplace	Number ($N = 14$)
Experts from UNESCO	Leader	1 Director (Expert 1)	3
	Member	1 Officer and 1 Assistant	
Experts from China	Leader	1 Professor (Expert 2)	7
	Member	2 professors, 2 associate professors, 1 postdoctoral researcher, and 1 doctor	
Experts from U.S.	Leader	1 Chief (Expert 3)	4
	Member	3 Researchers	

Textual analysis of policies for strategies and trends. Text analysis is a common research method in the field of social science, including topic modelling, data statistics, and more. Through these methods, it is possible to conduct an in-depth analysis of large amounts of textual data, revealing key information and trends within the text (Ke et al. 2023). The textual analysis method was adopted in this article, on the one hand, to support the rationality of the framework, and on the other hand, to expand the extension of the framework, explore policy for strategies and trends, and be more valuable for the construction of smart education.

Policy selection. The selection process was conducted in two rounds. In the first round, we identified the primary keywords for policy text retrieval, which included: "smart education", "digital education", "digital transformation", and "educational technology policy". These keywords were translated into the official languages of various countries and searched on the official websites of the Ministries of Education of those countries and international organizations, such as the Ministry of Education of China, the Department for Education of the United Kingdom, the United States Department of Education, the OECD, and others. Then, policy documents were included in the analysis if they met the following criteria (see Table 2). Finally, researchers retrieved 48 policy documents. In the second round, we selected the most representative policy of each country after duplicates were removed. 24 documents were deleted, leaving 24 documents (see Table 3).

Analysis process. In the first step of the textual analysis, the policies were read carefully to understand their overall objectives and content. Then, the policies were broken down into specific components, such as goals, strategies, and action plans.

In the second step, two researchers read the policies thoroughly and made coding according to the 9 dimensions of the first three leveraging points based on "National Smart Education Framework" outlined in section 4. During the process, the core indicators of each dimension were identified. Ultimately, 26 core indicators were used to code relevant content extracted from the texts. The two researchers compared their coding results and discussed any discrepancies to ensure consensus. Only codes that were consistently agreed upon were included in the final coding scheme.

The final step of the textual analysis involved interpreting the results and drawing conclusions about the policy trends in smart education. Frequencies of occurrence for 26 indicators were calculated to identify trends (see Table 4). Additionally, to

Table 2 Inclusion criteria and exclusion criteria.

Inclusion criteria	Exclusion criteria
Emphasize the application of technology in education	Not specifically targeted at the education sector
Issued by the Ministry of Education or other official union	Issued by social organizations or enterprises
Temporal restriction between January 2019 and May 2024	Excluding policies issued before 2019
Availability of a full-text document, such as a PDF	No specific text appears in the form of a webpage

Table 3 Smart education policies included for analysis.

Country/Organization	Policy Title	Published Time
China	Notice on the Recommendation and Selection for the "Smart Education Demonstration Zone" Construction Project	2019
Netherlands	Digitalisation agenda for primary and secondary education	2019
Nigeria	National policy on information and communication technologies (ICT) in education	2019
United Kingdom	Realizing the Potential of Technology in Education: A Strategy for Education Providers and the Technology Industry	2019
European Union	Digital Education Action Plan 2021-2027	2020
India	National Education Policy 2020	2020
Jordan	Executive action plan to integrate e-learning into the higher education system	2020
Singapore	Educational Technology Plan (2020-2030)	2020
South Africa	Report of a Ministerial Task Team on the Implications of the 4th Industrial Revolution for the Post-School Education and Training System	2020
Welsh	Enhancing digital resilience in education: An action plan to protect children and young people online	2020
Kenya	Policy on information and communication technology in education and training	2021
Maldives	ICT in Education Master Plan 2 2021-2024	2021
Africa Union	Digital education strategy	2022
Cameroon	Politique des TIC et Cadre Stratégique pour l'Education de Base au Cameroun	2022
Jamaican	ICT in education policy	2022
Korean	White Paper on ICT in Education in Korea	2022
Republic of Trinidad and Tobago	Digital Transformation Programme	2022
Saudi Arabia	Saudi Arabia's Digital and Distance Education	2022
UNESCO	UNESCO Institute for Information Technologies in Education Medium-Term Strategy 2022-2025	2022
Finland	Policies for the digitalisation of education and training until 2027	2023
French	Strategy for the digitalization of education 2023-2027	2023
Hungary	Ensuring Quality Digital Higher Education in Hungary	2023
OECD	Shaping Digital Education Enabling Factors For Quality, Equity And Efficiency	2023
United States	National Educational Technology Plan 2024	2024

facilitate a more intuitive comparison and analysis of the policies from various countries, we employed bubble charts, which help to delineate the differences and characteristics and illuminate the trends of national smart education policies.

National smart education framework

The four leveraging points of implementing forward-thinking policy, building smart digital learning environments, transforming teaching and learning, and overarching considerations were identified as the core elements of smart education, with 3 dimensions of each leveraging point (see Fig. 1). The framework aimed to modernize the digital learning ecosystem to truly provide inclusive and equitable educational opportunities to all students in this new era of learning. The National Smart Education Framework was approved by UNESCO Institute for Information Technologies in Education and the report of National Smart Education Framework was recommended on its website (UNESCO IITE et al. 2022).

Forward-thinking governance and policy initiatives. A modernized digital learning ecosystem requires a strategic, long-term commitment from government leaders to develop a national vision and plan for the effective use of educational technology, as well as adequate investments to ensure the plan's effective, sustainable implementation and continuous improvement.

Develop a national vision and plan. Government leaders commit to a shared vision that establishes the essential role that technology plays in ensuring students' future success and its implications for improving the nation's equitable social and economic conditions (Kioupi and Voulvoulis 2019). Stakeholders representing various sectors support government leaders in crafting a national educational technology plan—with established metrics and milestones for measuring progress, as well as associated initial, recurring, and hidden costs (Vital Wave Consulting 2008)—aligned to this vision.

Build infrastructure capacity. Government leaders deploy, maintain, and update advanced telecommunications and information services necessary to ensure that all communities, including those that are rural or otherwise remote, are connected to high-speed Internet (U.S. Department of Education 2017a; U.S. Department of Education 2017b).

Invest in human capacity (Darling-Hammond et al. 2017). Modernizing the digital learning ecosystem must involve modernizing the educator workforce, as large-scale investments to purchase

Table 4 The example of coding statistics.

Policy	Original text	Indicator (frequency)	Dimension (frequency)	Note
French: Strategy for the digitalization of education 2023–2027	"Integrating digital skills into educational curricula"	Enhance digital skills (+ 1)	Invest in human capacity (+ 1)	Develop digital skills by encompassing teaching programming, data analysis, and cybersecurity across various educational levels

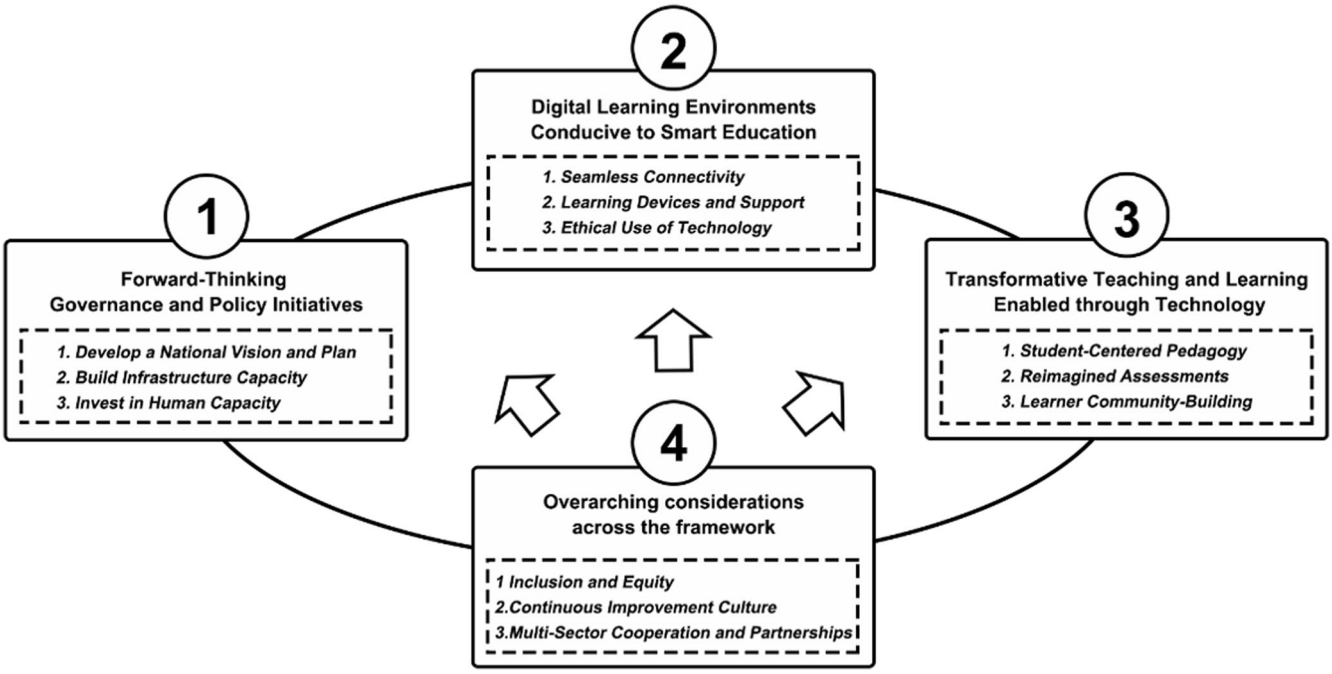

Fig. 1 National smart education framework.

educational technologies without human capacity considerations are less likely to truly transform how those digital tools and resources are used for learning.

Digital learning environments conducive to smart education. A modernized digital learning ecosystem requires an environment where both formal and non-formal education opportunities are enabled and accelerated by access to the necessary technology (UNESCO 2020). These digital learning environments allowed for learning to occur anytime and anywhere, whether the learner was on campus or otherwise (Matthew and Halgali 2019). In addition, the use of various technologies by leaders, educators, and students must be guided by a shared set of standards, rules, and guidelines around the ethical use of digital information.

Seamless connectivity. All students and educators are supported in becoming global collaborators through seamless Internet connectivity at school, at home, or in the community, freeing learners from artificial time-based or geographical constraints.

Learning devices and support. All students and educators are provided with access to a digital learning device conducive to smart education and capable of connecting to advanced telecommunications and information services (International Society for Technology in Education 2021).

Ethical use of technology (Mâță 2022). To realize the vision of smart education, personal and performance data must be shared between trusted individuals and entities. Systems must safeguard this data from misuse while ensuring that it is readily available to students, educators, and leaders who depend on it.

Transformative teaching and learning enabled through technology. A modernized digital learning ecosystem requires a renewed, shared understanding among leaders and stakeholders around what an effective educational experience transformed through technology looks like (Tri et al. 2021). This fundamental shift necessitates an in-depth look at improving pedagogy, assessments, and learner communities.

Student-centered pedagogy (U.S. Department of Education 2017c; National Academies of Sciences, Engineering, and Medicine 2018). Through the active, developmentally appropriate use of technology grounded in the learning sciences, educators design and deliver educational experiences for students to become empowered learners and digital creators who construct knowledge and develop metacognitive skills from early childhood to higher education and beyond. This may be achieved through implementing learning models that center student agency and provide students with multiple pathways for authentic learning beyond the physical classroom (Darling-Hammond et al. 2020).

Reimagined assessments (Sacramento County Office of Education 2021). Students co-establish their learning goals with educators and choose, with appropriate guidance, how to demonstrate their

Table 5 Coding results of the first leveraging point.

Dimensions	Indicators	Frequency
Develop a National Vision and Plan (DNVP, $n = 353$)	DNVP1-Promote high-quality, inclusive, and accessible education	130
	DNVP2-Create a high-performing digital education ecosystem	119
	DNVP3-Set visions for technology in learning	104
Build Infrastructure Capacity (BIC, $n = 311$)	BIC1-Increase Internet connectivity and access to digital tools	118
	BIC2-Improve digital services	104
	BIC3-Enhance effective investment	89
Invest in Human Capacity (IHC, $n = 310$)	IHC1-Enhance digital skills	154
	IHC2-Explore effective training methods	100
	IHC3-Offer artificial intelligence courses to cultivate AI literacy	56

mastery. Educators coach, support, and use adaptive measures and learning analytics to provide timely, individualized feedback.

Learning community-building (CASEL 2021; DigCitCommit Coalition 2021). Technology is leveraged as a critical tool to facilitate culturally responsive instruction, thereby instilling a sense of belonging and helping students grow as civic-minded members of the local and global community.

Overarching considerations. In implementing the three key leverage points in this framework, government leaders must place several overarching considerations at the forefront to ensure that the modernized digital learning ecosystem is agile, sustainable, and meets the needs of all stakeholders.

Inclusion and equity (UNESCO 2021). The needs of diverse student and educator groups are heard and addressed, and policies and approaches ensure full participation and inclusion. Diverse representation is featured in positions of key decision-making authority (Ainscow 2020).

Continuous improvement culture (Simmers 2021). Educators and leaders collaborate with stakeholders to continuously collect information, evaluate, and adapt and improve educational experiences to support the expanding vision of technology-empowered learning.

Multi-sector cooperation and partnerships (OECD 2012). Leaders leverage the wide, influential reach of the private and social sectors, higher education institutions, and other domestic and international NGOs to provide public services that promote transformative uses of technology for learning.

Strategies and trends of national smart education policies

Forward-thinking governance and policy initiatives. Data analysis reveals that the "Develop a National Vision and Plan" dimension is mentioned most within this leveraging point ($n = 353$, see Table 5), which demonstrates a trend towards developing digital education ecosystems for leveraging technology to adapt to the rapidly changing global educational landscape and foster the quality and equity of educational systems.

Develop a national vision and plan. The indicator of "Promote high-quality, inclusive and accessible education" ($n = 130$, see Table 5) is most mentioned within this dimension. It reflects a trend towards ensuring that smart education drives education towards higher quality and standards. In other words, in developing a national vision and plan, one of the global trends is to ensure that every citizen benefits from smart educational initiatives, achieving both the elevation of educational standards and the democratization of educational opportunities.

To visually present the frequency of each indicator across 24 policy documents, we draw the bubble chart (see Fig. 2). The size of the bubbles in the chart increases incrementally from the smallest point (representing 1 time) to the largest point (representing 10 times). The horizontal axis of the bubble chart represents different countries' policies, while the vertical axis corresponds to the various indicators.

As shown in Fig. 2, the indicator of "Promote high-quality, inclusive and accessible education", is mentioned 9 times in the Netherlands' *Digitalisation agenda for primary and secondary education*, which outlines five key strategic directions to enhance high-quality, inclusive, and accessible education: (1) innovation in learning by teachers and school leaders; (2) enhancing digital literacy among students and teachers, including foundational IT skills, media literacy, information skills, and computational thinking; (3) utilizing digital learning resources to support user work; (4) ensuring that infrastructure is secure, reliable, and future-oriented; (5) maintaining a continuous focus on the ethical issues related to the digitalization of education (Ministry of Education, Culture and Science of the Netherlands 2019).

The indicator of "Create a high-performing digital education ecosystem", is mentioned 8 times in the United Kingdom' *Realizing the Potential of Technology in Education: A Strategy for Education Providers and the Technology Industry*, which advocates that the overarching goal is to establish world-class education, training, and care for everyone. Meanwhile, the policy highlights five key areas of focus: administration processes, assessment processes, teaching practices, continuing professional development, and lifelong learning (UK Department for Education 2019).

The indicator of "Set visions for technology in learning", is mentioned the most in the Singapore's *Educational Technology Plan (2020–2030)* ($n = 9$, see Fig. 2). The vision of Singapore's educational technology plan, over the next 5 to 10 years, aims to use technology to foster more autonomous, personalized, connected, and human-centric education (Ministry of Education of Singapore 2020).

Build infrastructure capacity. The indicator "Increase Internet connectivity and access to digital tools" is mentioned the most within this dimension ($n = 118$, see Table 5), with Singapore's *Educational Technology Plan (2020–2030)* as the most mentioned policy ($n = 8$, see Fig. 2). It emphasises the need for schools to establish a learning environment that supports seamless learning, continuously improving information and communication technology infrastructure and systems to support teaching in both schools and homes. This approach involves reimagining learning spaces to enrich interactions beyond the traditional classroom setting, facilitating a broader scope of learning opportunities that extend outside conventional educational environments (Ministry of Education of Singapore 2020).

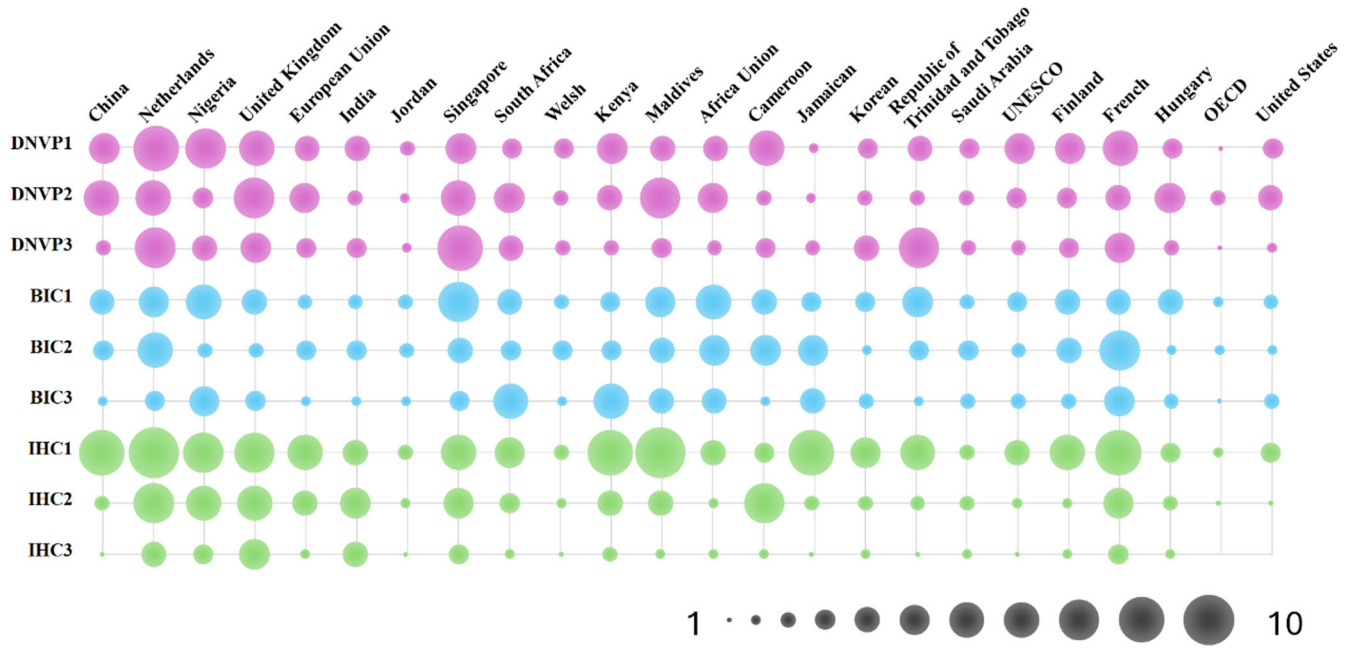

Fig. 2 Bubble chart of 24 policies in the first leveraging point. Notes: The connotation of DNVP1-DNVP3, BIC1-BIC3, IHC1-IHC3, please refer to Table 5.

The analysis indicates that enhancing network connectivity and the availability of digital tools are emphasized in the development of smart education infrastructure. It suggests that the expansion of smart education relies on addressing the digital divide and ensuring the equitable distribution of resources as foundational prerequisites.

Invest in human capacity. Within this dimension, the indicator of "Enhance digital skills" is mentioned the most ($n = 154$, see Table 5), which emphasizes that teachers' digital competence is central to advancing smart education. Countries have been conducting extensive research to investigate the structure of teachers' digital competence, with a major focus on enhancing their digital skills and exploring effective training methods with technical support for school leaders, teachers, and other stakeholders.

The indicator of "Enhance digital skills", is mentioned the most in Maldives's *ICT in Education Master Plan 2 2021–2024* ($n = 10$, see Fig. 2), which advocates for the development and implementation of ICT Competency Standards for Teachers with technical support, offering capacity-building training and workshop sessions tailored to the curriculum for both pre-service and in-service teachers (Ministry of Education of Maldives 2021).

Within the indicator of "Explore effective training methods", France's *digital education strategy for 2023–2027* sets specific AI competency requirements for students at different stages of their education: In elementary school, students focus on learning foundational mathematics through regular specialized educational activities both during and after school, along with the learning and use of basic digital tools. In middle school, students are expected to deepen their understanding of digital tools and their algorithms, and to develop preliminary coding skills. In high school, the introduction of artificial intelligence courses aims to further enhance students' capabilities in mathematics and computer science (French Ministry of Education 2023).

However, the enhancement of AI literacy is less mentioned in the selected policies. In less developed regions, initiating artificial intelligence courses and fostering awareness of AI literacy have not yet been prioritized in teacher training programs. Educational policies in these regions still tend to prioritize more established subjects such as traditional mathematics or reading, considering the educational impacts of AI as relatively novel. Governments and educational institutions are still in the early stages of developing AI capabilities and have not yet effectively integrated AI into their educational and training curricula.

Digital learning environments conducive to smart education. Data analysis reveals that within this leveraging point, the "Ethical Use of Technology" is the most mentioned dimension ($n = 193$, see Table 6), which indicates that the construction of smart education learning environments prioritizes the "Ethical Use of Technology" as a foundational principle.

Seamless connectivity. Within this dimension, the indicator of "Promote fair and equal access to the Internet" is mentioned the most ($n = 75$, see Table 6). It highlights a global trend of increasing emphasis on widespread and equitable access to the Internet.

The indicators of "Increase Wi-Fi coverage rate" and "Promote fair and equal access to the Internet" are widely mentioned across the European Union's *Digital Education Action Plan 2021–2027* (see Fig. 3). Drawing on lessons from the COVID-19 crisis, the European Commission proposed a Council Recommendation on online and distance learning for primary and secondary education by the end of 2021. Following this, member states have established and improved digital network infrastructure in school buildings to achieve full Wi-Fi coverage in schools, ensuring network coverage across the country (European Commission 2020).

Learning devices and support. Within this dimension, the indicators of "Enhance the utilization of digital devices", "Pool open educational resources", and "Build public service platforms" are mentioned 56, 54, and 43 times respectively (see Table 6). The average mention in the 24 policy documents does not exceed 3 times, with a maximum of 4 times (see Fig. 3), which indicate that device allocation and learning supports for students have not been highly emphasized in lots of policies.

The indicator of "Build public service platforms", is mentioned the most in *Saudi Arabia's Digital and Distance Education* ($n = 4$,

Table 6 Coding results of the second leveraging point.

Dimensions	Indicators	Frequency
Seamless Connectivity (SC, $n = 189$)	SC1-Promote fair and equal access to the Internet	75
	SC2-Provide high-speed, convenient, free, and safe network services	61
	SC3-Increase Wi-Fi coverage rate	53
Learning Devices and Support (LDS, $n = 153$)	LDS1-Enhance the utilization of digital devices	56
	LDS2-Pool open educational resources	54
	LDS3-Build public service platforms	43
Ethical Use of Technology (EUT, $n = 193$)	EUT1-Ensure information security and privacy	82
	EUT2-Guarantee the availability, integrity, confidentiality, and security of data in cyberspace	57
	EUT3-Develop ethical guidelines on AI and data usage	54

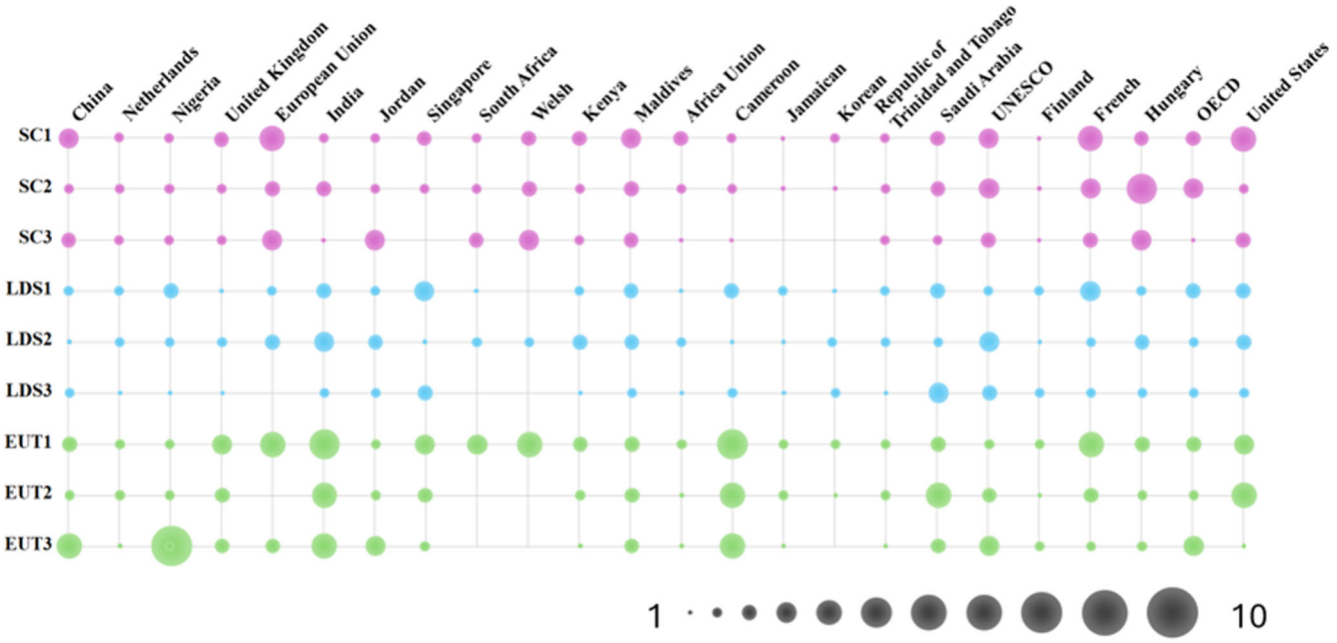

Fig. 3 Bubble chart of 24 policies in the second leveraging point. Notes: The connotation of SC1-SC3, LDS1-LDS3, EUT1-EUT3, please refer to Table 6.

see Fig. 3), which emphasizes enhancing regional cooperation and communication through its Madrasati platform, which supports collaborative solutions for educational continuity, such as developing training programs and establishing reliable assessment methods for learning. Additionally, there is a focus on integrating Madrasati with other essential platforms, like NOOR, to streamline educational information and services (World Bank Group 2022).

Ethical use of technology. Within this dimension, the indicator of "Ensure information security and privacy" is mentioned most ($n = 82$, see Table 6), indicating that countries are increasingly aware of the risks associated with cybersecurity and privacy breaches in smart learning environments. The steady development of smart education should be predicated on ensuring data security and addressing ethical issues. In Wales, the *Enhancing Resilience in Digital Education policy* focuses on developing online safety tools, resources, and activities to protect children and young people from illegal and harmful content online (Welsh Government 2020).

French's *Strategy for the digitalization of education 2023–2027* mentions that the Pix 6 device certification courses includes a specific module on "protection and security", covering the safeguarding of digital environments, personal data, and privacy, as well as health, well-being, and the environment (French Ministry of Education 2023).

Transformative teaching and learning enabled through technology. Data analysis reveals that the dimension of "Reimagined Assessments" is most mentioned within this leveraging point ($n = 224$, see Table 7), which emphasizes that reforming the evaluation methods by technological support is becoming a focal point in the development of smart education.

Student-centered pedagogy. The indicator of "Implement new pedagogies such as blended learning, human-computer collaborative teaching, and immersive virtual teaching" ($n = 82$, see Table 7) is mentioned most within this dimension, which indicates a consensus among nations on offering students immersive and personalized educational experiences through modern technology and innovative methods that cater specifically to their needs. *The Report of a Ministerial Task Team on the Implications of the 4th Industrial Revolution for the Post-School Education and Training System* in South Africa highlights the potential of educational approaches using technology to support teaching and learning in various forms such as online learning, blended learning courses, MOOCs, and AI integration into learning delivery to create personalized learning opportunities, depending on the curriculum context and needs (Department of Higher Education and Training Republic of South Africa 2020).

The indicator of "Provide students real-time feedback and personalized learning experiences", is mentioned the most in the

Table 7 Coding results of the third leveraging point.

Dimensions	Indicators	Frequency
Student-Centered Pedagogy (SCP, $n = 209$)	SCP1-Implement new pedagogies such as blended learning, human-computer collaborative teaching, and immersive virtual teaching	82
	SCP2-Provide students real-time feedback and personalized learning experiences	76
	SCP3-Make students' learning data to achieve personalized teaching	51
Reimagined Assessments (RA, $n = 224$)	RA1-Emphasize critical thinking, problem-solving, and creativity	97
	RA2-Harness technology for learner-centered assessments	67
	RA3-Record and analyze the data of learning process	60
Learner Community Building (LCB, $n = 155$)	LCB1-Develop digital citizens	97
	LCB2-Cooperative learning and co-creation among students	58

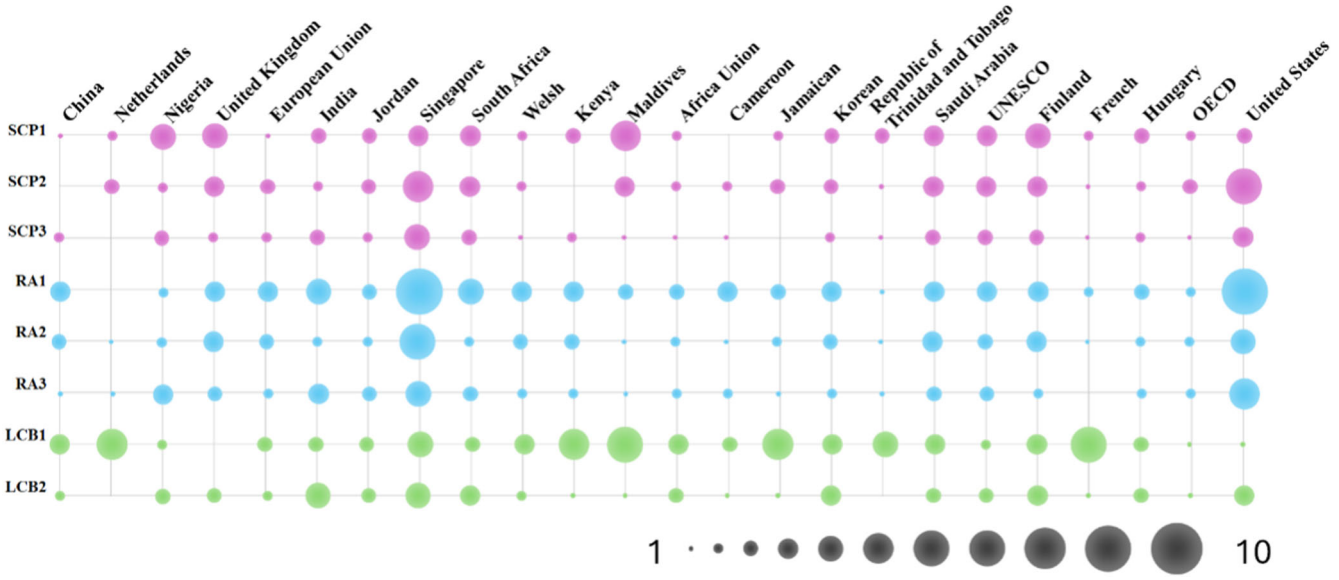

Fig. 4 Bubble chart of 24 policies in the third leveraging point. Notes: the connotation of SCP1-SCP3, RA1-RA3, LCB1-LCB2, please refer to Table 7.

United States *NETP 2024* ($n = 7$, see Fig. 4). In the United States, a variety of technological tools are utilized to deliver feedback and personalize learning. For instance, teachers provide direct feedback through chat boxes during online courses, with individual feedback sent via email or directly to students' mobile phones. Additionally, teachers create WhatsApp groups for each class, where students can ask questions and receive explanations and feedback during the course. In terms of personalized learning experiences, students actively engage with various types of multimedia content such as audio, video, and infographics (U.S. Office of Educational Technology 2024).

Reimagined assessments. Within this dimension, the indicator of "Emphasize critical thinking, problem-solving, and creativity" ($n = 97$, see Table 7) is mentioned most, indicating that cultivating higher-order thinking skills is becoming the common consensus in developing smart education policies. The *NETP2024* mentions 8 times of this indicator, emphasizes that students should actively use technology to discover, analyze, and apply learning, rather than passively receiving information. Meanwhile, schools are encouraged to develop a "Profile of a Learner/Graduate" outlining cognitive, personal, and interpersonal competencies students should have when transitioning between grade levels and graduation. Meanwhile, the *NETP2024* also emphasizes "Record and analyze the data of learning process"($n = 6$, see Fig. 4), which highlights the use of technology to implement personalized assessments. Various online assessment tools allow teachers to conduct real-time oral tests and use video and audio recordings of students to evaluate their performance. Additionally, digital tools such as Quizizz, Padlets, and WordWall are utilized for self-assessment activities, which enable students, particularly in higher grades, to access question banks and support both learning and performance evaluation, enhancing the effectiveness of educational assessments by integrating technology (U.S. Office of Educational Technology 2024).

Learner community building. Within this dimension, the indicator "Develop digital citizens" ($n = 97$, see Table 7) is mentioned most, which indicates that "digital citizen" has become a critical element of concern, yet the level of attention varies significantly from countries.

As shown in Fig. 4, only a select number of countries have explicitly referenced the integration of digital technologies within learning communities in their policies. The *NETP 2024* advocates for building new learning spaces (such as STEAM labs, maker spaces, and innovation creation labs) to provide students with authentic learning experiences to cultivate essential skills such as collaboration and problem-solving. (U.S. Office of Educational Technology 2024). Singapore's *Educational Technology Plan (2020–2030)* supports students in expanding their learning horizons and enriching their educational experiences by connecting with the community and the world at large (Ministry of Education of Singapore 2020).

Overarching considerations. The overarching considerations should be considered in implementing the above three leveraging

points, which could not be coded as these dimensions should be integrated with all the elements of the above-mentioned indicators. Through textual analysis, several significant initiatives that represent the direction of sustainable smart education development will be presented in the following part.

Inclusion and equity. Ensuring inclusive and equitable access to smart education has become a pressing issue for many governments, as the digital divide remains a significant barrier to achieving this goal. In response, many countries have launched initiatives to provide smart education for all, particularly vulnerable groups such as students living in rural areas.

The U.S. National Educational Technology Plan 2024 addresses three key digital divides from the perspectives of content, teachers, and students: the Digital Access Divide, the Digital Design Divide, and the Digital Use Divide. The Digital Access Divide focuses on the unequal opportunities for students to access digital resources; the Digital Design Divide highlights the challenges teachers face in designing and implementing digital education; and the Digital Use Divide concentrates on the disparities in how students use digital tools and technologies for learning (U.S. Office of Educational Technology 2024).

However, addressing the digital divide is only the first step towards achieving inclusive and equitable smart education. Governments must also ensure that digital education is tailored to meet the diverse needs of all learners, including those with disabilities and from marginalized communities. They must also consider issues related to the quality of digital education and ensure that it is of the same standard as traditional classroom learning.

Continuous improvement culture. Countries worldwide are investing in strategic plans that promote continuous improvement culture through a series of plans focusing on integrating emerging technologies into education, leading to transformative changes in teaching and learning.

The U.S. Department of Education regularly issuing the *National Educational Technology Plan (NETP)*, sets out a national vision and plan for learning enabled by technology (U.S. Office of Educational Technology 2024). The NETP is updated every five years, starting in 1996, and addresses emerging topics in educational technology with continuous culture. South Korea also implemented five-yearly plans about ICT in education since 1996 and summarizes their work every year to formulate an annual implementation plan for the next year. Singapore MOE also released four educational technology plans since 1997, with the latest EdTech Plan being a blueprint for developing an ICT-enabled learning and teaching environment to transform the learning experience for students (Ministry of Education of Singapore 2020).

Multi-sector cooperation and partnerships. Multi-sector cooperation and partnerships are essential for effectively implementing smart education, as various organizations can bring their strengths and resources to the table. Governments, universities, and social organizations around the world recognize the importance of cross-sector collaboration and actively explore cooperation mechanisms.

In the UK, for example, *Enhancing Digital Resilience in Education in 2018* emphasizes the need for cross-sector and public-private sector cooperation (Welsh government 2020). The Department for Education establishes an Education Technology Leadership Group with the Department for Business, Energy, and Industrial Strategy to put innovative technology ideas into practice and increase its engagement with businesses to help schools purchase and embed technology.

Through multi-sector cooperation and partnerships, organizations can work together to achieve shared goals and maximize their impact. This trend is likely to continue in the future, as smart education continues to evolve, and stakeholders recognize the importance of collaboration in achieving success.

Discussion, conclusion, and future research

In response to the challenges posed by the current educational crisis, it is crucial to reform the systems and mechanisms for digital governance, establish an ecosystem for smart education development, and cultivate digital capabilities for all. Smart education has become an important strategy for building a smart society, and creating a National Smart Education Framework is essential for achieving this goal. This framework should include forward-thinking governance and policy initiatives, as well as considerations for digital learning environments and transformative teaching and learning enabled through technology.

Although smart education has significant potential to increase the quality and efficiency of education, there will be some hurdles in the implementation process, and the implementation effect differs in different locations and schools (Naik et al. 2020). When formulating smart education policies, it is necessary to fully consider the economic development level, digital learning environment and teachers' digital competence.

According to the bubble chart from Figs. 2 to 4, We found that indicators on Forward-thinking governance and policy initiatives were generally mentioned more often, but indicators on digital learning environments were mentioned relatively less. This can be explained by the fact that countries elevated the idea of integrating technology into education to the level of national policy, but there may be difficulties in the actual construction of a digital learning environment due to economic inputs. The level of economic development restricted the implementation of smart education in economically underdeveloped countries. In order to implement smart education, countries with different economic levels can have different construction priorities. According to the National Smart Education Framework, for example, the economically underdeveloped regions can focus on developing a national vision and plan and building infrastructure. Infrastructure investment was a key factor in the development of education (Psacharopoulos 1988). As for economically developed countries with well-developed infrastructure, it was necessary to focus more on investing in human capacity to achieve the development of teachers and students. Wilson et al. (2021) verified that human capacity had a conditional indirect impact on smart education through the mediating variable of leadership capacity. The National Smart Education Framework was a universal framework that was suitable for various types of countries, and although all aspects of the framework cannot be implemented at the same time, each country can have its own focus according to the economic situation.

Focus on the leveraging point of digital learning environments conducive to smart education, which had relatively weak awareness, we found that building public service platforms was the least mentioned among all indicators (see Fig. 3). In the implementation of digital education, the inadequacy of the digital learning environment was a common and critical problem. First, the Internet infrastructure was not perfect, the network coverage was limited, and the bandwidth was insufficient in some remote areas, which could not support the platforms. Cui et al. (2023) confirmed that network bandwidth and coverage were critical for the implementation of digital education, but in many regions, this basic condition had not been met. Second, the lack of hardware equipment made it impossible for students to participate in online service. In the Global Education Monitoring Report, for example, UNESCO (2023) found that only one in two people in low-income countries had a mobile phone, and one-third did not use the Internet, which also proved the two challenges above.

Therefore, until these issues are effectively addressed, the technologies may be public and beneficial for all.

What's more, we found that enhancing digital skills in investing in human capacity was the most mentioned indicator (see Fig. 2). As we can see, all countries attached great importance to the development of the digital skills of humans in the education system, including teachers, students and so on, which was also a current trend. Teachers' digital competence was one of the key elements for the implementation of smart education. ElSayary (2023) conducted a 10-week training program that effectively boosted teachers' digital competencies and contributed to students' innovative use of digital technologies. Digital competence referred not only to teachers' skills to master digital technology but also to teachers' competence to flexibly use digital technology for instructional design, management, and classroom implementation (Hämäläinen et al. 2021). Therefore, governments can improve teachers' digital literacy and teaching capabilities by carrying out various forms of training activities, such as online and offline training courses, seminars and lectures, and case sharing (Lin et al. 2023).

Although different countries may take different approaches, there are converging themes that can serve as a guide for developing a National Smart Education Framework. These themes include a wide range of governing philosophies, education structures, funding and public-private partnership strategies, and countries of varying sizes, cultures, and complexity. The National Smart Education Framework represents a distillation of some of the most impactful approaches implemented around the world to transform teaching and learning with the power of technology. This study provides a valuable resource for governments and other key stakeholders around the world to develop national plans for intelligent technologies in education or update existing plans to address emerging challenges and opportunities. The implementation of a National Smart Education Framework can lead to a more efficient and effective education system, better-equipped learners, and a workforce ready for the challenges of the 21st century.

Due to the scope of the study, there are still some limitations in this study, which need to be addressed in future studies. Firstly, the expert Delphi method and textual analysis are used to complement each other to determine the rationality and reliability of the national smart education framework. The research method is mainly qualitative research, and the quantitative research of this framework will be further strengthened in future research. Second, the sample size of policy textual analysis includes 24 countries, not covering most countries in the world. As the follow-up research continues, we will continue to collect new policies released by each country for analysis and update the research progress. Finally, our findings call for the construction and in-depth study of smart education for leaders and educators in various countries. Therefore, further empirical research could be carried out in future research to test the effectiveness of smart education.

Data availability

Data is available within the article or its supplementary materials, which contain the 24 policy source documents mentioned in the article.

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Author contributions

JY: project administration; conceptualization; formal analysis; methodology; original draft; and review & editing. YS: data curation; formal analysis; methodology; and review

& editing. RL: data curation; formal analysis; and original draft. HZ: review & editing. All authors above read and approved this final manuscript.

Competing interests
The authors declare no competing interests.

Ethical approval
All procedures performed in this study were in accordance with the ethical standards of the university. Ethical clearance and approval were granted by the Ethics Committee of the School of Education in Hangzhou Normal University (China) (No. 2022028) on June 20, 2022. Experts participating in the study gave informed consent to participate voluntarily.

Informed consent
Informed consent was obtained from all the participants.

Additional information
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