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ANALYTICAL REPORT ON THE GLOBAL INNOVATIONS AND MONITORING OF THE STATUS OF SMART EDUCATION

ANALYTICAL REPORT ON THE GLOBAL INNOVATIONS AND MONITORING OF THE STATUS OF SMART EDUCATION

Moscow, 2022

UDC 37+316.772.5
LBC 74.202
A53

This work is a co-publication produced by the UNESCO Institute for Information Technologies in Education, Higher School of Economics, and Beijing Normal University within the joint project "Rethinking and Redesigning National Smart Education Strategy" led by Prof. Ronghuai Huang from Beijing Normal University and Director Tao Zhan from UNESCO IITE.

A53 **Analytical Report** on the Global Innovations and Monitoring of the Status of Smart Education [Electronic Resource] / UNESCO IITE; HSE University; BNU. — Electronic Text Data (1 MB). — Moscow: HSE University, 2022. — ISBN 978-5-7598-2808-2.

UDC 37+316.772.5
LBC 74.202

Authors: Natalia Amelina, Irina Dvoretskaya, Olga Romanova, Kirill Savitsky, Galina Udayadas, Alexander Uvarov, Junfeng Yang, Rongxia Zhuang.

ISBN 978-5-7598-2808-2 (e-book)

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ACKNOWLEDGEMENTS

Numerous specialists and organizations have contributed to the production of this report, which was coordinated jointly by the UNESCO Institute for Information Technologies in Education (UNESCO IITE) and Beijing Normal University (BNU).

The organizers are very grateful for the advice and support of colleagues at Beijing Normal University who participated in expert workshops: Prof. Ronghuai Huang, Prof. Junfeng Yang, Dr Tingwen Zhang, Dr Rongxia Zhuang, Dr Wei Cheng, Dr Shaofeng Wang, Dr Yunwu Wang, Ms Mandy Wan, Ms Chloe Chen and Ms Jian Hu. Helpful feedback was received from colleagues at HSE University: Prof. Alexey Semenov, Prof. Isak Froumin, Dr Ivan Karlov, Dr Vyacheslav Bashev, Dr Alexander Chepovskii, Mr Danil Fedorovykh, Mr Rustam Baiburin, Dr Ilia Prahov. Feedback from Dr. Alexander Giglavy (Lyceum 1533, Moscow, Russia) is appreciated. The extensive support of Ms Anna Polyanskaya (HSE) is highly appreciated. The research team also acknowledges the support and coordination of UNESCO IITE team, including Dr. Tao Zhan, Dr. Natalia Amelina and Ms. Galina Udayadas.

The organizers highly appreciate the contribution of experts who provided essential support for the development of this report: Ms Irina Dvoretskaya (HSE), Ms Olga Romanova (HSE), Mr Kirill Savitsky (HSE) and Prof. Alexander Uvarov (HSE).

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ABBREVIATIONS

AR	Augmented reality
BNU	Beijing Normal University
BYOD	Bring your own device
BYOT	Bring your own technology
CRM	Customer relationship management
DT	Digital Technologies
GEM	Global Education Monitoring
HSE	Higher School of Economics
ICT	Information and communications technology
IoT	Internet of Things
MOOC	Massive open online course
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
SDG	Sustainable Development Goal
SEE	Smart education environment
SES	Smart education system
SL	Smart learning
SLE	Smart learning environment
SS	Smart school
STEM	Science, technology, engineering and mathematics
UIS	UNESCO Institute for Statistics
UNESCO IITE	UNESCO Institute for Information Technologies in Education

EXECUTIVE SUMMARY

This report is part of a UNESCO IITE – BNU joint project entitled 'Rethinking and Redesigning National Smart Education Strategy', which aims to reshape educational ecosystems and ICT education policies in different countries by achieving an analytical understanding of the role of ICT in education. This report was prepared under the Implementation Partners Agreement between UNESCO IITE and HSE University.

While smart education is postulated as a system employing innovative techniques, methods and instruments for developing new or enhanced educational processes, there is an absence of trustworthy, high-quality data and defined procedures for developing relevant and internationally comparable indicators of smart education. This makes it difficult for policymakers to draw conclusions or demonstrate greater commitment to incorporating digital technologies into their education systems.

In the present report, a team of experts from HSE University examines the key components for monitoring the status of smart education, including indicators, methodology and guidance. This report attempts to identify well-known educational concepts and specific indicators that could be used to put in place internationally accepted guidelines for monitoring and measuring the transition to smart education. In view of the continuously changing nature of digital technologies, this document should be considered as a live resource that would be refined and updated in the future.

This report aims to refine and expand the core set of smart education indicators for the purposes of tackling a broader range of policy problems relating to education system transformation. It proposes a set of qualitative and quantitative indicators for monitoring and evaluating the status of smart education and an index methodology for providing a clear structure for indicators, computing indices and making actionable policy recommendations.

In terms of its practical implications, this report should serve as a reference and guide for collecting smart education data at the national level and conducting surveys on smart education.

INTRODUCTION

Today, rapid developments in technology are driving the widespread use of digital technologies in almost every sector. It is expected that school education will also gain new opportunities and advantages from new educational technologies and methods. Smart education aims to alter traditional teaching, learning and school management within the smart environment.

UNESCO is committed to achieve the SDGs by improving educational quality around the world. Sustainable Development Goal (SDG) 4 recognizes that inclusive and accessible education is one of the foremost methods of achieving the SDGs (United Nations Development Programme, 2020). As a vital and integral part of the broader 2030 Agenda for Sustainable Development, SDG 4-Education 2030 sets down a new roadmap for educational development. To track progress toward the SDGs, the Global Education Monitoring Report (GEM) examines educational development. Supplementing the GEM with smart education indicators will help to describe global and national progress toward smart education.

The present report aims to

1. Strengthen the smart education conceptual framework by analysing the essential components of smart education identified across various frameworks and models of smart education.
2. Identify the main concepts of smart education and develop an operational definition of smart education at the global level.
3. Propose a list of qualitative and quantitative indicators for measuring the transition to smart education.
4. Develop an index methodology for monitoring and evaluating the status of smart education.
5. Draft guidelines for monitoring and measuring the transition toward smart education with the use of the best monitoring and evaluation practices.

1. GLOBAL INNOVATIONS IN SMART EDUCATION: AN ANALYTICAL REVIEW

Smart education uses data and technologies to enhance efficiency, sustainability and high educational outcomes for students. It is an ambitious concept that is being continuously refined today. Numerous studies and literature reviews on smart learning have appeared. Despite the growth of research on smart education and its conceptualization, systems of indicators for smart education are seldom discussed. The studies examined highlight the absence of terminology for breaking down the transition process to smart education/smart schools into its parts. This leads to a lack of consensus in this highly multidisciplinary field.

To bridge this gap and elaborate a comprehensive set of smart education indicators, the research team started with a mixed quantitative-qualitative review of recent publications in the smart education field as the first step toward defining smart education. Even though the idea of smart education is widely discussed today (Tikhomirov, 2011; Omidinia et al., 2013; Lapchik, 2013; Mason et al., 2019; Rybicheva, 2020; Li and Wong, 2021), there are still few published descriptions of practical cases of the transition to smart education. As the following analysis shows, developing accurate descriptive terminology that reduces confusion is an important prerequisite for the smart transformation of mass schooling. Furthermore, specifying terms in adjacent areas of education and learning will make the discussion more productive (Shemshack and Spector, 2020).

Four important concepts for further operationalization have been identified: smart education, smart learning, smart learning environment, and smart school. Each term will be explained in the following sections, and its relations to the others examined. The analysis of these terms cast the foundations for a systematic evaluation of the research literature.

METHODOLOGY FOR THE ANALYTICAL REVIEW OF SMART EDUCATION

This study takes an interdisciplinary approach to smart education. To represent the different aspects of smart education and smart schools, the research team chose to begin with a systematic literature review.

This led to a comprehensive overview of the determinants and key features of smart education and its related concepts in the interdisciplinary scientific landscape.

This review mainly followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher et al., 2009) with minor adjustments. The latter were introduced to ensure a multidisciplinary view of smart schools and smart education. This framework was chosen to make the study transparent and replicable for the future identification and synthesis of all available relevant research on smart education.

The query executed for the literature review was threefold. It took smart education and related concepts as the determinants. A comprehensive search was conducted in the Web of Science and Scopus, which, taken together, covered a wide range of research literature.

For optimal results, Boolean search strings were constructed. The search and selection procedures are presented in Figure 1.

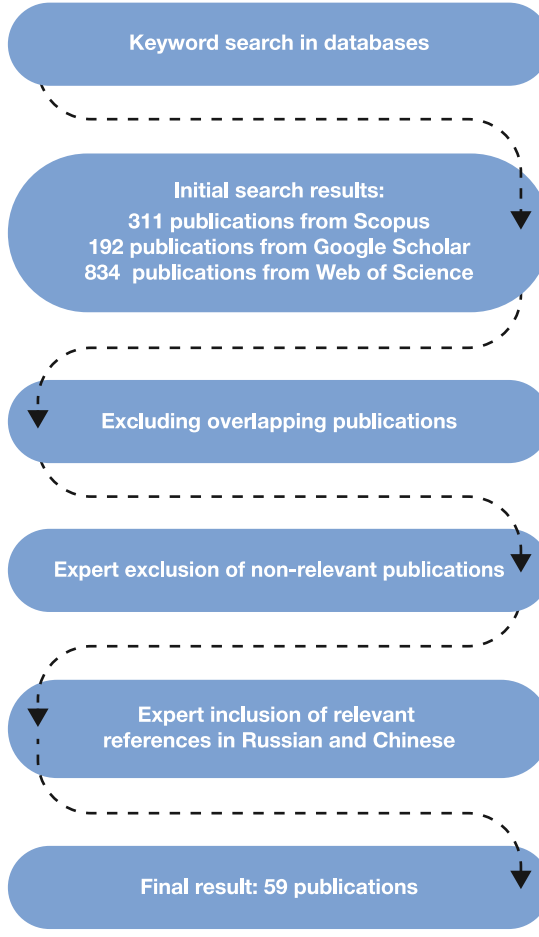

Figure 1. Publication analysis framework

MAIN RESULTS OF THE SYSTEMATIC LITERATURE REVIEW

SMART EDUCATION CONCEPT

The impact of digital technologies (DT) on the educational process has interested international researchers for decades. Researchers and educators have recently introduced the concept of 'smart education' to describe a brand-new approach to teaching, learning, schooling and the organization of the education system. To determine the role of smart education and gain a better understanding of this concept, different approaches taken by researchers to this multidisciplinary field are considered.

According to the analytical review, there exist several different definitions of smart education that reveal its main features and characteristics.

First of all, it should be said that the concept of smart education was not the first attempt to describe the processes of introducing digital technologies into the educational context. For this reason, some researchers consider smart education from the standpoint of its similarities and differences with related concepts (for example, ICT-supported learning, blended learning and mobile learning), asserting that a comparison of these concepts will lead to a more explicit definition of smart education itself (García-Tudela et al., 2021).

Huang (2014) proposes a three-layer structure of smart education: a smart environment, a new learning model and a modern education system. Diversified and personalized support to educational stakeholders (students, teachers, parents, etc.) is delivered based on gathered data on teaching and learning. In this definition, top-down factors (such as an evidence-based education system) play a clear role. The definition proposed by Huang views the smart education system as being oriented on the changing external context. It would also be expedient to conceptualize the transformation of the education system into a learning organization. This would also imply that the transformation of a traditional education system into a smart education system is related to the transformation of the broader system as well as to the changing interaction between the different constituents of this system.

The role of the top-down approach in mapping changes in the education system and educational organizations highlighted by Huang is also supported by Zhu et al. (2016), who offer a paradigm of smart education with three key components: smart environment, smart pedagogy and smart learners. They argue that the ideology of smart education consists of better educational goals, while smart pedagogy and the smart learning environments support the development of smart talents (Figure 2).

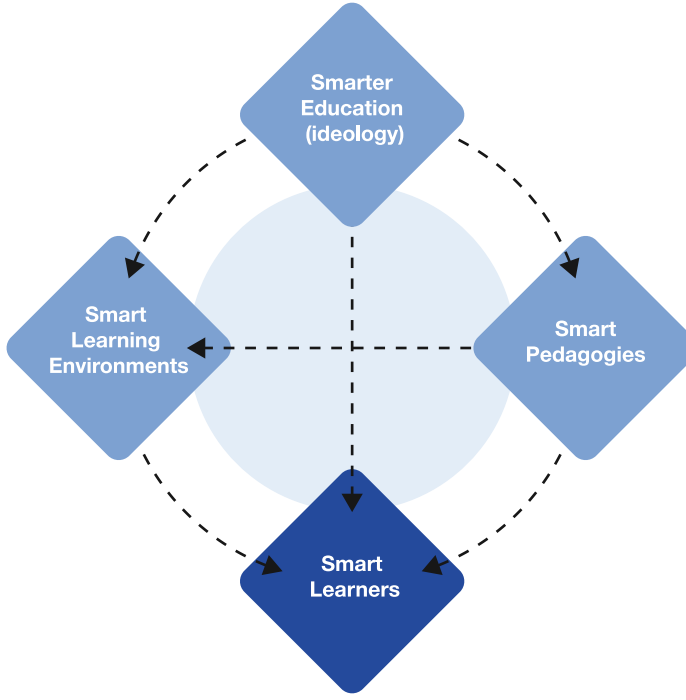

Figure 2. Research framework of smart education (based on Zhu et al., 2016)

This definition implicitly focuses on the close link between SES and SEE insofar as the SES is involved in the development and implementation of smart solutions within the education system. Just as Huang's approach, Zhu and his colleagues' definition highlights the important role of smart en-

vironments in transforming teaching and learning. While the SES component is not explicitly present in the definition, it would be logical to highlight it, emphasizing the leading ideological role of SE.

Zhu et al. propose using four levels to measure the abilities of smart learners:

- Basic knowledge (reading, writing, STEM subjects);
- Comprehensive skills (critical thinking, problem-solving skills);
- Personalized experience and expertise (digital literacy, creativity, innovative skills);
- Collective intelligence (ability to communicate and work on a team).

Focusing on smart pedagogies, the authors consider four strategies for organizing learning:

- Class-based differentiated instruction;
- Group-based collaborative learning;
- Individual-based personalized learning;
- Mass-based generative learning.

It is clear that the transition to smart education requires changes in teaching and learning in a flexible physical and virtual environment. The key role of pedagogy in smart education highlighted previously (Zhu, et al., 2016; Wa, 2017) was further elaborated by Daniela (Daniela, 2019). The framework proposed by the latter focuses on the student, who becomes 'smart' in the digital environment. This is suggested by the criteria that smart pedagogy (a broader concept than smart education) should fulfil:

- Didactical principle calling for addressing individual learning goals through a personalized and context-defined approach;
- Cognitive development approach coherent with the proximal development zone and constructivist principles;
- Socio-emotional development that conforms to the expectations of students and helps to ensure cooperation in target groups;
- Physical development that aligns with the sensory development of students.

Subsequent conceptualizations were built on previous work in this area and attempted to systemize the issue of smart education. The definition proposed by Singh and Miah (2020) focuses on the transformation of teaching and learning in the smart environment. Examining the corpus of smart education studies, the authors identify the most promising digital technologies. However, due to the lack of goal-oriented and process-oriented components, technology becomes the main element of this definition. Furthermore, the latter does not address the functionality of digital solutions from the perspective of smart education.

A similar systematizing and research-based definition was proposed by Martin et al. (2019), who choose the following key elements to represent the technology-enhanced environment of smart education: connectivity, security, prediction systems and data visualization. Nevertheless, this definition is also limited to the technological environment of smart education.

The aforementioned conceptualizations mainly focus on teaching and learning and their environment and on educational outcomes. Their lack of organizational and management aspects is overcome in a definition proposed by Tikhomirov et al. (2015), who identify three main dimensions: educational outcomes, ICT, and organizational aspects.

The educational outcome component mentioned by Tikhomirov et al., among others, covers different types of cognitive skills, including critical thinking, cognitive self-organization and systems thinking, as well as other aspects of learning that assist in improving these skills. The ICT dimension consists of such features as integrity, interactivity, social interaction tools and mobility. Software for the development of educational content is also included in the ICT dimension. In the proposed model, the organizational dimension is shaped by smart educational programmes and the opportunities provided by open education. This dimension can be practically implemented with the help of knowledge management, individualization and customization supported by learner profiles. In fact, smart teaching and learning are incorporated into the organizational dimension through the inclusion of project learning, informal learning, and multiple organizational forms and approaches (Tikhomirov et al., 2015).

Highlighting the organizational aspect of smart education, Tikhomirov et al. emphasize the role of systemic factors and mechanisms for providing smart education, which play an important role at the level of the education system.

Table 1 gives a synthesis of results according to the dimensions of each model analysed in the analytical review.

Table 1. Key dimensions of smart education

№	Element of smart education	Authors
1	Combination of physical and virtual environments and infrastructure	(Huang, 2014), (Wa, 2017)
2	Smart pedagogy	(Zhu et al., 2016), (Daniela, 2019)
3	Smart leaning environment	(Huang, 2014), (Zhu et al., 2016), (Tikhomirov et al., 2015)
4	School management and organization	(Tikhomirov et al., 2015)
5	Evidence-based education system (smart education system)	(Huang, 2014)
6	Personalized learning	(Huang, 2014)
7	Smart educational outcomes	(Tikhomirov et al., 2015), (Daniela, 2019)
8	Smart (intelligent) technologies	(Singh and Miah, 2020)
9	Smart professional development	(Tikhomirov et al., 2015)

From the standpoint of its key dimensions, smart education can be defined as a process that is founded on evidence-based (result-based) teaching and learning and carried out with the guidance and support of a smart education system in a smart learning environment.

Smart learning

Following the analysis of the conceptualizations and frameworks of smart education, one should note that the concepts of smart learning and the smart learning environment are also inseparable from smart education. For this reason, it would be expedient to examine the concept of smart learning, which helps to reveal the changing roles and responsibilities of students and teachers and shifts in goal setting and instructional approaches.

According to Poulova and Klimova (2015), the paradigm of smart learning has moved from e-learning to mobile learning (m-learning). Consequently, 'smart learning' can be characterized as a larger concept that encompasses both current and future technology-based learning.

This thesis was previously advanced by Kim et al. (2013), who focused on ubiquitous learning in which an everyday learning environment is supported by mobile devices and wireless networks. However, smart learning combines the benefits of social learning and learner-centric and service-oriented educational paradigms rather than solely relying on the use of digital equipment.

In contrast to the attempt of Kim et al. to embed the digital environment into the concept of smart learning, Liu et al. (2016) note that smart learning is not provided by a smart digital environment alone. They propose the following characteristics of smart learning:

- The learner is positioned in the centre;
- The learning experience ensures that students can learn easily and effectively at their own pace;
- The system provides supporting technologies, such as adaptive technologies with tracking facilities;
- The basic principles of teaching and learning tie together learning activities and the learning environment.

In their systematic review, Li and Wong (2021) analyse the trends of smart learning research. Discussing the gaps, they point to a lack of studies dedicated to effective teaching and learning in the smart learning environment. At the same time, they speak of a growth of research on collaborative learning, which may be linked to the importance currently attached to cooperation in society.

To highlight the key elements of smart learning, the basic concepts of smart learning proposed by different researchers (Table 2) were analysed. The closely linked concepts of smart education, smart learning environment and smart schools were chosen.

Based on the analysis of the key concepts of smart learning, the latter can be defined as a new learning model supported by technologies with the following characteristics:

- Smart devices and intelligent technology are widely used. At the same time, some researchers mention technologies as a prerequisite for the implementation of SL yet note that technologies remain an auxiliary element.
- Seamless (continuous) learning and the opportunity to learn anytime, anywhere, in any way and at any pace are implemented.
- The focus is on learners and their needs, which means the implementation of personalized learning.
- Various data (learning progress, student results, logs from digital platforms) is recorded and analysed, and data-based feedback (formative assessments, assignment tailored to the needs of students, etc.) is provided.
- Smart learning resources (MOOC, micro-lessons, mobile courseware, electronic textbooks) are widely used.

Table 2 presents the most relevant key features of smart learning identified through the analysis of the latter's definitions. This list of key features is designed to map and model smart leaning in a broad sense and has a strong orientation toward the functionality of the learning process. Its main purpose is to organize the results of the analysis and highlight the crucial aspects of the process of smart learning for the subsequent development of an operational definition of smart education.

Table 2. Key elements of smart learning

№	Element of smart learning	Authors
1	Temporal-spatial A4 model of learning, where A4 is: • Anytime • Anywhere • Any way • Any pace	(Huang, 2014)
2	Smart devices (artificial intelligence, wearable technologies), intelligent technologies (cloud computing, learning analytics, big data), IoT, AR	(Gros, 2016), (Yuping and Xiao, 2020), (Hwang, 2014)
3	Provision of feedback or guidance to students	(Yuping and Xiao, 2020), (Hwang, 2014) (Gros, 2016)
4	Learner-centricity in teaching and learning	(Liu et al., 2016)
5	Seamless learning	(Zhu et al., 2016)
6	Personalized learning	(Huang, 2014), (Wa, 2017)
7	Use of smart resources in learning	(Yuping and Xiao, 2020)

Smart learning environment

The smart learning environment (SLE) is identified as a key prerequisite of smart education. The scope of its definition is wide – from a technical representation (Putro et al., 2018) to a pedagogical one (Dron, 2018; Lorenzo and Gallon, 2018). The main conceptualizations of SLE are listed below.

Hwang (2014) defines SLE as a technology-enabled environment. A key feature of the smart learning environment is adaptiveness based on learning data and data-driven personalized support (e.g. guidance, feedback, tips, or tools) for learners. Data such as logs, footprints, academic records and online data is shaping the context that drives the learning process (Figure 3). This definition focuses on the technological side of SLE and depicts a conceptual architecture for it.

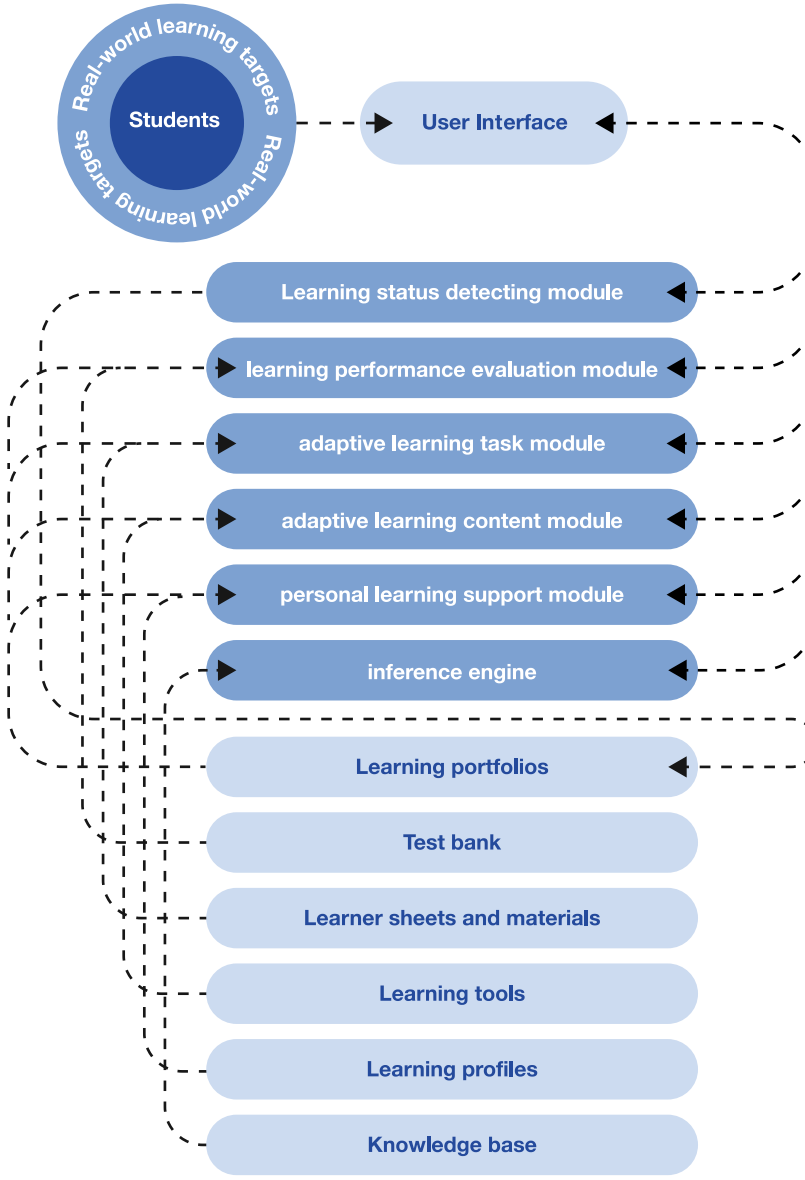

Figure 3. Framework of a smart learning environment (based on Hwang, 2014)

Close attention is also paid to technology by Koper (2014), who identifies SLE as a technical system with adaptive features constructed for more effective learning. The idea of human learning interfaces is applied to SLE as a universal tool that helps to adjust the system to the learning theory behind the design (Figure 4).

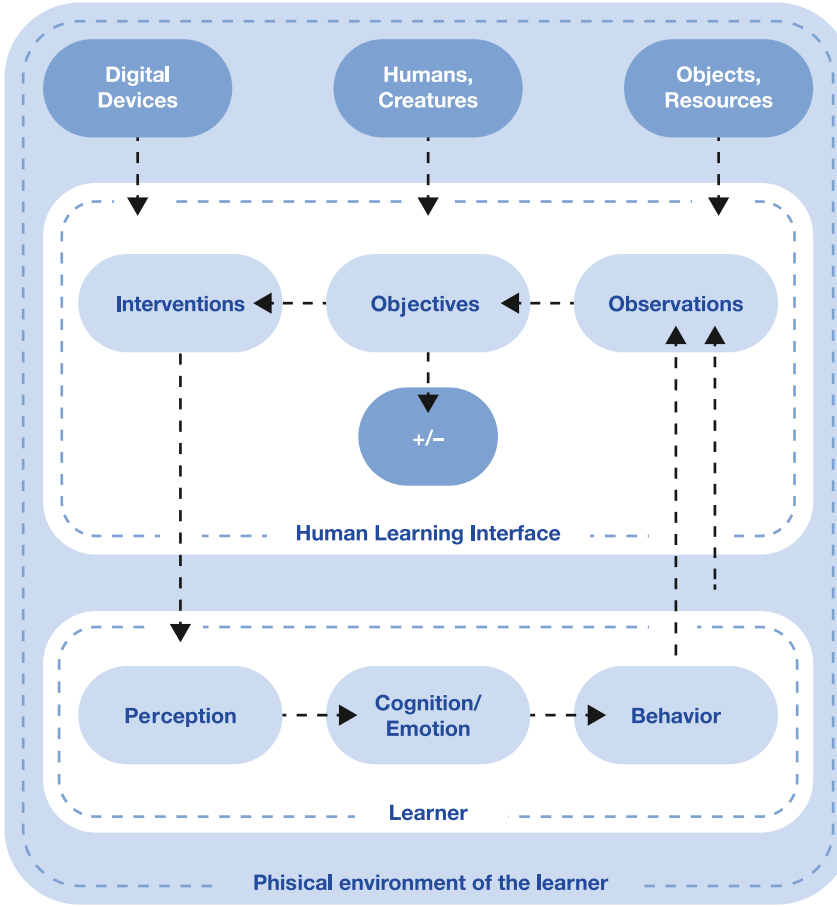

Figure 4. SLE framework (based on Koper, 2014)

A more learning-oriented definition is given by Hwang (2014), who argues that smart learning supported by SLE offers more advanced options than ubiquitous or adaptive learning. According to Hwang, smart learning in SLE can support effective teaching and learning. Continuing this conceptualization of SLE, Hwang et al. (2015) define the following key features of a smart learning environment:

- It is an environment that provides personalized learning support based on learners' online and real-world status. 'In advance' (or predictive) support is also a feature of SLE.
- An SLE system should offer students instant and adaptive support based on their individual needs from different perspectives such as academic performance, learning behaviour, learning patterns, profiles, personal factors, etc. – both in the virtual space and in the real world in which they are situated.
- An SLE system has an adaptive interface that considers user needs and profile. This interface is used on multiple devices that teachers and users employ.

This definition gives a picture of functional requirements with a strong pedagogical orientation. At the same time, neither of Hwang's definitions contains practical examples of the implementation of such an approach to SLE or gives nominal definitions for examples of features.

Spector (2014) considers the three concepts 'smart', 'environment', and 'learning' separately and describes the real-world situations in which they occur. With regard to the idea of the 'smart learning environment', he notes that such environments can be tailored to students and personalize teaching in a more effective, efficient and attractive way, accounting for differences in the students' initial levels of knowledge and skills, personal experiences and other interests (Figure 5). This definition brings together different concepts from pedagogy and gives clear guidelines for practical SLE solutions.

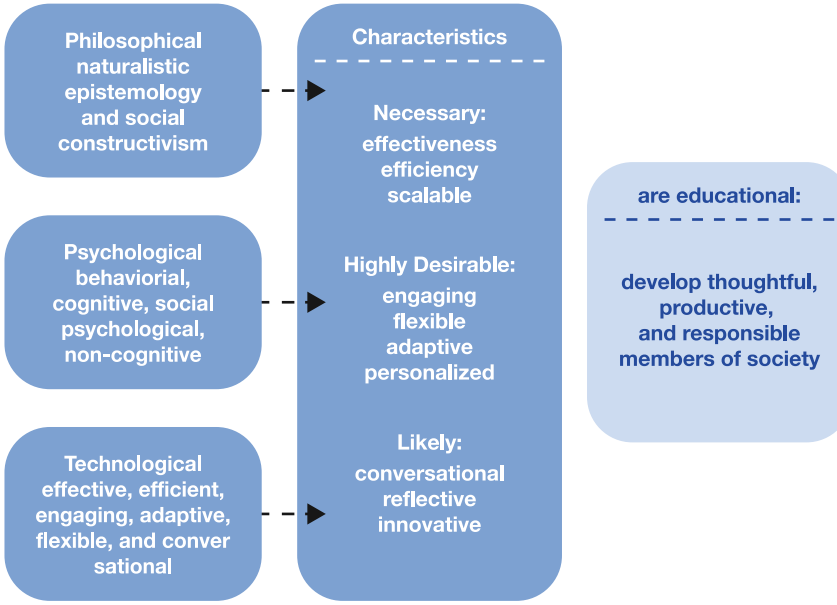

Figure 5. Smart learning environment framework (based on Spector, 2014)

Starting from high-level drivers that shape SLE, Spector proposes a set of characteristics that the design of a smart environment should take into account (Spector, 2014):

- The goal of effectiveness is attained by setting learning outcomes. The impact of SLE can be measured against a non-smart learning environment with a similar number of students.
- The efficiency of SLE is defined by its cost-effectiveness. Spector suggests using a metric of five years rather than a non-smart learning environment with a comparable number of learners.
- The scalability of SLE is defined as the ability of a system to expand to a larger scale (from classroom to school, from school to region) without modifying its architecture and design.
- The autonomy of SLE refers to the ability to catch different learning situations and activities of students.

Another further conceptualization of SLE is proposed by Peng et al. (2019), who identify the core elements of personalized learning that are enabled by smart learning environments.

Spector's definition essentially provides a detailed list of functional requirements for digital solutions. While the definition's psychological and philosophical characteristics potentially set the upper-level requirements for specific digital solutions, it does not specify which teaching approaches and strategies should be implemented in SLE.

Given that teachers need to employ a variety of teaching strategies in SLE, Huang et al. (2013) focus their definition of SLE on the idea of the personalization of learning spaces. This work defines the smart learning environment as a special learning space that can accommodate different learning situations, distinguish learner characteristics, provide appropriate learning resources and convenient interactive tools to learners, and measure learning outcomes in order to facilitate effective student learning. A key aspect of Huang's definition that is important for the future development of an operational definition of smart education is its focus on the existence of learning spaces (virtual and physical).

The idea of flexible time and spatial structures for learning in SLE is continued by Gros (2016), who writes that SLE elaborates the idea of anytime-anywhere learning thanks to a rich digital infrastructure, proactive guidance and on-demand support. Analysing the key features of SLE suggested in previous works, Gros proposes a practical approach to SLE design. An important part of this approach is its participatory orientation that gives teaching and learning actors an important role in SLE development. Gros's definition emphasizes the importance of the SLE characteristic of the provision of anytime-anywhere learning for SE. This orientation can promote a design-based approach to SLE (Gao et al., 2019), which opens new methodological perspectives.

SLE features of anytime-anywhere learning that can help to use smart teaching practices for smart educational goals are detailed in frameworks prepared by Zhu et al. (2016) and García-Tudela et al. (2021).

Zhu et al. (2016) describe SLE as follows:

1. Location-aware: in smart learning, the student's real-time location gives critical data that systems require for adaptation and adjustment purposes.
2. Context-aware: in a smart learning environment, there is a continuous investigation of different activity circumstances and information.
3. Socially aware: in a smart learning environment, the social relationships of students are taken into account.
4. Interoperability: to run a smart learning environment successfully, standards and protocols are needed to transfer data between different platforms and services.
5. Seamless connection: a reliable and stable connection is needed for all actors and devices
6. Adaptability: learning resources are adapted to student access, preferences and needs.
7. Ubiquitous: a learner's demand is predicted until it is explicitly expressed, providing learners with a visual and transparent approach to access learning resources and services.
8. Whole record: learning path data are captured for further analysis that provides reasonable assessments, suggestions and on-demand services.
9. Natural interaction: data on multimodal interactions include information from position determination, facial expression recognition, etc.
10. High engagement: rich multimodal and multidirectional interactions create high engagement in the technology-saturated environment.

The definition by Zhu et al. strongly suggests the need to consider and evaluate social awareness supported by SLE.

The SLE-5 framework presented by Garcia-Tudela et al. (2021) includes five dimensions:

- Educational curriculum;
- Enriched methodologies and strategies;

- Enriched assessment;
- Educational roles;
- Smart technology.

It should be noted that the SLE-5 model focuses on basic characteristics without proposing specific indicators or detailed processes. At the same time, the SLE-5 model describes a clear hierarchy of changes, which has practical significance for reflection and evaluation and casts the foundations for the future development of indicators.

Moreover, this definition points to a close relationship between SLE and SES in terms of the development and use of curricula and external and internal methodological support for teachers.

Based on the aforementioned concepts, it is possible to say that a smart learning environment is an ecosystem that supports smart education and helps to implement its main ideas.

Thus, the properties that characterize smart education include:

- Adaptability, that is, a quick response to the requests of stakeholders (teachers, students, parents, managers) and adaptation to their requirements.
- Personalization, that is, the ability to personalize learning in accordance with the personal needs and capabilities of students.
- Effectiveness of learning: smart education is cost-effective and helps to improve learning outcomes.
- Responsiveness, that is, the ability to write, read and analyse data and monitor processes at the micro and macro levels to provide appropriate support.

Along with these properties, one frequently highlights the prerequisites without which smart education cannot exist:

- Use of modern information technologies. At the same time, most authors agree that smart education is more focused on digital educational content and learners than on technology. Technologies are

simply the means for implementing the concept of smart education;

- Smart and intelligent learning environment;
- Up-to-date teaching methods with a focus on personalization;
- Facilitative teachers who provide students with individualized instruction;
- Smart management system.

To summarize, specialists in this field claim that smart education is the dominant idea in the ICT in education and that, as a result of these processes, the education system is undergoing dramatic shifts that may lead to education reform. Some authors discuss the transition from a traditional learning environment to SLE (Dron, 2018). A thematic analysis to identify the key components of SLE from a research perspective was conducted, as shown in Table 3.

In view of the great variety of approaches to defining SLE, a hierarchy of key elements of SLE is suggested. Four top-level elements were highlighted: learning in SLE, the spatial aspect of learning in SLE and the spatial functionality of SLE, the technological aspect of SLE, which mostly relates to the provision of effective ways of teaching and learning, and the participatory aspect of SLE, which refers to the interactivity of teaching and learning strategies.

The results of the analysis of key descriptors offer relevant insights into major features of SLE, which can be further used during the operationalization step. The following features deserve particular mention:

1. **Space for seamless learning:** this feature is supported by the ability of SLE to provide interaction between teachers and students anytime and anywhere in both physical and virtual environments.
2. **A hardware system** guided by digital architecture that enables more effective learning (in terms of educational outcomes) through the use of smart mobile devices.
3. To ensure that the curriculum is in line with **real-world situations**, SLE supports a context-aware approach to learning.

An in-depth analysis of key concepts allows us to identify the basic elements of SLE (Table 3). The main motivation in the presentation of results is to describe the main aspects of the SLE process in terms of descriptors for the future development of an operational definition of smart education. In view of the fact that there is no SLE definition that fully and explicitly shares the level of consideration of key changes (global, national, regional, school-level), at this stage of the analysis such consideration is acceptable for the purposes of further construction of the operational definition. One can therefore propose the following hierarchy of descriptors and sub-descriptors.

Table 3. Elements of the smart learning environment

№	Descriptor	Short definition of descriptor aspects	Authors	Sub-descriptors	Authors
1	SPACE	Special learning space that can accommodate different learning situations, distinguish learner characteristics, provide appropriate learning resources and convenient interactive tools to learners, and measure learning outcomes in order to facilitate effective student learning	(Huang et al., 2013)	Functionality of seamless and adaptive learning in both virtual and physical spaces	(Huang et al., 2013)
		Both in the virtual space and in the real world	(Hwang et al., 2015)	Physical Environments	(Hoel and Mason, 2018), (Koper, 2014)
				Technology-enabled environment (virtual space that actively provides students with the necessary learning guidance)	(Hwang, 2014)

№	Descriptor	Short definition of descriptor aspects	Authors	Sub-descriptors	Authors
2	TECHNO-LOGY	Technical system with adaptive features constructed for more effective learning	(Koper, 2014)	Technology enriched environment (for example, classrooms equipped with technological infrastructure)	(García-Tudela et al., 2021)
				Autonomy of the smart learning environment	(Spector, 2014)
				Scalability of the smart learning environment	(Spector, 2014)
				Adaptiveness based on learning data	(Hwang, 2014)
				Design-based approach	(Gros, 2016), (Gao et al., 2019)
				Data-driven personalized support	(Hwang, 2014)
				Human learning interface	(Koper, 2014)
3	LEVEL OF PARTICI-PATION	User interface to real-world learning targets	(Hwang, 2014)	Participatory orientation	(Gros, 2016)
				Meta-activities (practice, reflection)	(Hoel and Mason, 2018)

№	Descriptor	Short definition of descriptor aspects	Authors	Sub-descriptors	Authors
4	LEARNING	Anytime-anywhere learning with a rich digital infrastructure, proactive guidance and on-demand support	(Gros, 2016)	Learning outcomes	(Spector, 2014)
				Learning instance	(Hoel and Mason, 2018)
				Philosophical, psychological and technological characteristics	(Spector, 2014)

Smart school concept

While the concept of the smart school helps to describe the changes taking place at the school level, it would be more expedient to include it in an operationalized definition of smart education. To get a better understanding of the 'smart school', some approaches to defining this concept were examined.

Yuping and Xiao (2020) characterize the smart school as a school equipped with a high-speed wireless network, technologies for integrating online and offline learning, a face recognition system, and temperature and humidity control. This definition gives an idea of the necessary technological equipment without describing its impact on learning. As Wang et al. (2019) point out, the smart school integrates fundamental infrastructure, operating systems, and educational resources that enable the interchange of data, information and knowledge and serve as an important link in the implementation of smart education.

On the other hand, Ali et al. (2009) approach the smart school from the standpoint of day-to-day school routines, defining the smart school as a systematically updated educational institution in terms of teaching, learning, and school management practices that prepares learners for the informa-

tion age. This definition does not give an understanding of specific changes and their direction at the school level. In contrast, Hwang (2014) claims that the modern school fosters a learning environment that provides students with all the learning guides, tips, suggestions and support tools they need.

A more detailed view is proposed by Huang et al. (2012), who list the following characteristics of a smart school (smart campus):

1. The ability to provide personalized services for teachers and students;
2. The ability to perceive the physical and virtual (digital) environments;
3. The ability to distinguish between learning situations and account for the individual characteristics of each student;
4. The ability to ensure a stable internet connection;
5. The ability to analyse and evaluate teaching and learning processes.

While the external context of the smart school is not mentioned in the definitions cited above, it is taken into account by Williamson (2014). In his definition, the smart school is inextricably linked with smart cities (external smart environment) and smart citizens (smart local community). Williamson considers the concept of the big data-driven school, in which supportive real-time feedback and predictive recommendations provide a personalized educational experience for students. Such a school should have the following digital environment:

- Online courses that permit the continuous monitoring and tracking of learners via real-time data;
- E-textbooks that 'learn' from their use by students and provide feedback to teachers;
- Adaptive learning systems that employ automated real-time analysis to adjust content to specific student needs;
- Customized 'playlists' created by an algorithm;
- New types of data analysis that collects data from student behaviour, learns from it, and forecasts the future performance of each student.

The description of the smart school proposed by Taleb and Hassanzadeh (2015) is based on the concept of personalized learning. The authors assert that a smart school strives to make learning more engaging, motivating, stimulating and meaningful for students. To do so, it uses a mix of learning strategies to ensure a mastery-based approach and promote holistic development. Teachers in smart schools adapt learning styles to individual needs and create a classroom environment compatible with different teaching and learning strategies.

Describing the model of a school with a personalized learning approach, Wa (2017) define the smart school (or smart campus) as a new type of institution based on the traditional school that creates a virtual space focused not only on the internal infrastructure of the school but also on the entire surrounding world. The space and functions of the traditional school are expanded through the use of advanced digital technologies to include all the resources and services of the surrounding educational environment. This leads to more effective teaching and learning. Both of these definitions add to the understanding of the changes taking place in teaching and learning.

To understand the practical work taking place in a smart school, it would be expedient to analyse the definition used by Project Zero – a project initiated by the Harvard Graduate School of Education to explain learning in a changing world. The following components are proposed for the smart school mode (Smart Schools | Project Zero, 2021).

1. Careful consideration of which academic and transdisciplinary content should be unlocked in each student's potential
2. Inculcating a school-level lifelong learning culture and teaching higher-order thinking in subjects
3. Prioritizing student work for understanding
4. Mastery-based teaching
5. Learning-centred assessment
6. Embracing complexity
7. The school as a learning organization

The definition proposed by Project Zero exploits the concept of the school as a learning organization, which has become a powerful tool for school management in a rapidly changing environment (Kools and Stoll, 2016) for attaining the goals of mastery-based teaching and learning. Even though the Project Zero definition does not contain any digital-related characteristics, it represents the results of over 30 years of localizing schools in a constantly evolving context. Just as the definition given by Ali, Nor, Hamzah and Alwi (2009), the Project Zero definition highlights the importance of conducting systematic work for effectuating the transition to the smart school.

The examination of different definitions of the smart school makes it clear that this concept is closely linked to smart education. It is essential for the further operationalization of smart education and the possible operationalization of real-life school practices. Despite the fact that the considered definitions mostly focus on the technical environment, it would be incomplete to say that the smart school is a school that uses smart digital resources. An analysis of the definitions of the smart school from the perspective of smart education shows that teaching and learning transformation in a smart school should be guided by the renewal of educational outcomes based on SLE and higher order thinking.

Table 4. Elements of the smart school

№	Element of the smart school	Authors
1	The school as a learning organization	(Ali et al., 2009), (Smart Schools | Project Zero, 2021), (Kools and Stoll, 2016)
2	Personalized services for teachers and learners	(Huang et al., 2012)
3	Mastery-based teaching	(Taleb and Hassanzadeh, 2015), (Smart Schools | Project Zero, 2021)
4	Rich digital environment	(Williamson, 2014), (Wang et al., 2019)
5	Connectivity	(Ye and He, 2020)

This table presents the most relevant elements of the smart school. It highlights the conditions that must be met at the school level for making the transition to the smart school: organization (transition to a learning organization, availability of personalized services for teachers and students), technology (connectivity, rich digital environment) and pedagogy (mastery-based teaching). Given the insufficient conceptualization of the smart school (especially in comparison to SE and SLE), it may be expedient to transfer key characteristics from other concepts for the purposes of operationalization and the development of indicators.

In the context of change management and the introduction of smart education, the idea of school as a learning organization plays a key role in the successful transition from a traditional mode of schooling to the smart school. The focus on developing a culture of lifelong learning can help to bring about positive changes in schools.

2. OPERATIONAL DEFINITION OF SMART EDUCATION: MAIN CONCEPTS

The concept of smart education makes it possible to introduce the concept of the school digital renewal process (SDRP) for tracking the transition of schools and the education system from the traditional school and education system (in all their variations) to the SS and SES models. A conceptual definition of smart education must describe the relationships between its sub-concepts. This leads us to the following definition of smart education:

Smart education is an educational process provided by smart schools in smart education systems at the regional/country level with the help of a smart educational environment (Figure 6).

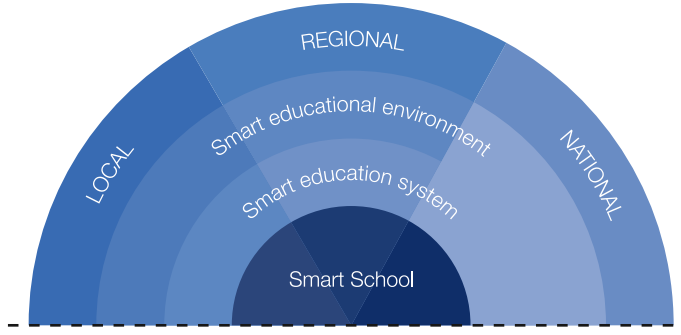

Figure 6. Conceptualization of smart education

SMART SCHOOL (SS)

Short definition. A smart school (SS) is an educational organization operating in an SES that implements a system of personalized learning using the potential of SEE. It takes an evidence-based approach to the comprehensive development of EVERY student ensuring a basic level of educational outcomes that are necessary for life in a digital society, including academic performance and cognitive and socio-emotional skills.

A smart school has the following key characteristics:

- The SS is the main production unit (educational organization) in the SES (at the national/regional/municipal level)
- The SS is a learning organization that develops dynamically and systematically by using the constantly developing potential of the digital educational environment and by responding to the changing socio-economic context. The smart school is able to adjust the following, when necessary:

— Goals and curriculum as well as organizational forms and teaching methods

— System of personalized (personal and professional) staff development and methodological support for teachers

— Procedures, business processes and responsibilities of employees, organizational structure, educational environment, etc.

- The SS works closely with the local community (serving as its cultural and educational centre), authorities, parents and business representatives for supporting and developing the local SEE to improve the educational outcomes of students and the cultural development of all members of the local community
- The SS receives all-around support (moral, intellectual, personnel, financial and material) from the local community to attain the required learning and educational outcomes for all pupils and to allow the latter to perform their cultural and educational functions in the local community.

SMART EDUCATION SYSTEM (SES)

Short definition. A smart education system (SES) is an education system (at the municipal/regional/national level) operating in an SEE that systematically guides and supports the processes of establishment/closure of educational organizations and their successful functioning, development and transformation into smart schools. The SES includes, but is not limited to, educational authorities and their legal framework, inspectorates and curricular services; institutes for the development of pre-service and in-service teachers; and SEE partners and SEE support and development services.

A smart education system has the following key characteristics:

- A vision of SES as a learning system that develops dynamically, responding on a daily basis to the changing demands of life, and augments, assimilates, and uses the constantly developing potential of the digital educational environment to change its educational policy, organizational structure and methods of work, as necessary;
- The SES takes part in the creation and development of SEE that would be adapted for updating the education system and creating and developing SS and SES;
- The SES aspires to transform and adjust traditional school buildings and capacities in order to meet SS and SEE requirements through the implementation of educational policies;
- The SES supports the creation and development of a system for monitoring the processes of digital renewal that can assess the progress of digital education renewal and the effectiveness of management decisions and programmes as well as providing targeted support to schools for their transformation into smart schools and their further development;
- The SES supports the transformation of in-service and pre-service teacher training institutions into smart educational organizations that train educators (teachers, administrators, etc.) at the necessary level for the full involvement of young specialists in the formation and development of SS and SES;

- The SES supports the creation and development of

— Digital educational and teaching materials and digital tools and services furthering the goals and content of general education at the different stages of its reform.

— Systems of personalized professional development of in-service teachers that support the design and implementation of highly productive organizational forms and methods of teaching and learning (in particular, with the help of digital materials, tools and services).

SMART EDUCATIONAL ENVIRONMENT (SEE)

Short definition. A smart educational environment (SEE) is a growing ecosystem that includes multi-platform services and digital devices, educational and teaching materials, tools and services (**virtual component**), educational spaces, infrastructure, materials, tools and services (**physical component**) and a social environment (inside and outside the school). The SEE is designed to support the educational process, the successful functioning of schools and the education system, and their transformation into SS and SES and further development.

A smart educational environment has the following key characteristics:

- The SEE (portals of personalized learning – PLP) supports the formation and development of a school with personalized services (through the transformation of all working processes in the school), including:

— Sets of itemized, detailed and operationalized educational results (corresponding to the requirements of educational standards) that are modified, refined and supplemented by SS teachers.

— Redundant and constantly updated e-libraries of digital educational and teaching materials and digital tools and services that cover the needs of all participants in the educational process.

— Tools (specialized CRM systems) for the formation of personal work (curriculum) plans of all participants in the educational process

(students, teachers, administrators), their activity histories, and evidence of their achievement of their educational and production results.

- The SEE provides information support for all SS and SES business processes, updates centralized matrices on the fulfilment of responsibilities by all the participants of the educational process (students, teachers, administrators) and prepares information materials and recommendations for making management decisions for SS and SES executives at all levels.
- The SEE supports all workflows relating to the engagement of SS in the community, including outreach and feedback channels. SEE provides SS students and parents with a summary of all learning and education activities in which the learner is involved both in and outside of school (extracurricular sports, music, technology, theatre, etc.). The SEE offers customized and targeted guidance for students, parents and educators on assessing student workloads and building balanced daily routines for them.
- The SEE continuously monitors the digital renewal of regional education (as an integral part of the functioning of the education system), compiles information on its results and makes targeted SS recommendations for improving its work.

Closer analysis and evaluation show that four concepts are essential for measuring and defining the transition to smart education in national contexts: smart education, smart school, smart education system, and smart educational environment. Taken together, they help to clarify indicators of the status of the monitoring and evaluation of smart education.

3. INDICATORS FOR MONITORING AND EVALUATING THE STATUS OF SMART EDUCATION

APPROACH TO FORMULATING SMART EDUCATION INDICATORS

As smart education is considered to be an educational process provided by smart schools in a smart education system at the regional/country level using the smart education environment, the concept of the school digital renewal process (SDRP) is used. This concept helps to describe the transition of the school and the education system from the traditional school and education system in all its variations to the smart school and smart education system models.

These indicators are formulating using the results of the analytical review and operational definition proposed in the foregoing stages of the project. Focus and expert group interviews were also used to accumulate expertise and verify the validity of the list of indicators and their definitions.

METHODOLOGY OF FORMULATING EXPERTISE-DRIVEN INDICATORS

Indicators are proposed, assessed and validateed on the basis of an initial set of indicators for smart education derived from materials studied previously in the project. A combination of focus groups and expert group interviews were used for data collection to promote the generation of ideas.

Focus groups and group interviews were organized in three steps using a list of concepts prepared beforehand. Each step was followed by the work of an expert group, which collected and evaluated every indicator against the operational definition and its dimensions, examining its measurement methodology and possible data sources.

1. DEVELOPMENT OF A SYSTEM OF SMART SCHOOL INDICATORS AT THE REGIONAL LEVEL

A group of school leaders was invited to participate in the process of formulating a system of smart education indicators at the regional level. This offline event took place in Voronezh in December 2021 as a part of two-day training seminar organized by the Voronezh Institute of Educational Development and attended by 84 school administrators from 42 schools of the Voronezh Region (principals and deputy principals representing each municipality of the Voronezh Region).

During the event, the participants were divided into six equal groups, each of which was asked to propose and present a system of indicators for evaluating the transition process to the smart school at the regional level based on a specific point of view. Three points of view were proposed (two groups worked independently on each point of view):

A) Regional department of education;

B) Regional ministry of digital development;

C) Regional parent community.

The indicators were developed with the help of a general framework that included three main groups:

- Indicators showing the changes taking place in the digital environment of the school;
- Indicators showing the changes taking place in teaching and learning;
- Indicators showing changes in school management.

Each group presented an elaborated system of indicators, after which the participants participated in an open vote on the proposed indicators to assess the feasibility and importance of their evaluation for tracking changes taking place in schools at the regional level.

The indicators generated by these brainstorming activities were then presented to the expert panel of the project. The experts assessed the expediency of putting these indicators on the general list of smart education indicators.

2. SERIES OF BRAINSTORMING SESSIONS WITH EDUCATORS ABOUT THE SMART SCHOOL INDICATOR SYSTEM

A series of online brainstorming sessions was held in December 2021 within the framework of the project to work out a proposal on smart education indicators for the expert group. Educators with solid practical experience in schools were involved in the brainstorming sessions. In particular, deputy directors of large schools in Moscow and St. Petersburg, school teachers, and managers of companies in the field of extracurricular education for children took part in the sessions. In all, four events, each lasting two hours, were held to examine different issues relating to smart education indicators. The number of participants varied from five to eight in each session, with 12 individuals participating in all (one expert could be a member of several brainstorming groups).

The participants of the sessions were given the following materials to help them prepare for the events:

A) Materials prepared during previous stages of the project;

B) Texts of articles drafted in parallel projects by the project team (in particular, the article by Uvarov et al. (2021));

C) UIS materials, including materials relating to SDG indicators and the preparation of the 2021 Global Education Monitoring Report on Technology and Education.

The proposal and attribution of indicators were based on a framework that specified three main groups of processes that can be described with indicators:

- Indicators showing the changes taking place in the digital environment of the school;
- Indicators showing the changes taking place in teaching and learning;
- Indicators showing changes in school management.

During the first part of the brainstorming activity (sessions 1 and 2), the participants immersed themselves in the context of smart education and made proposals for smart education indicators from various perspectives.

During the first stage, the participants, randomly divided into two groups, proposed indicators for describing a smart school from the point of view of a teacher or school administrator. At the same time, the participants were tasked at this stage with correlating the indicators with specific processes taking place in schools.

During the second stage, the same groups of participants were tasked with describing the specific processes taking place in a school in terms of:

- Parents (Group 1);
- Potential future employers of students (including universities, vocational education systems and companies) (Group 2).

At the same time, the experts were not asked to formulate specific indicators that could be correlated with the proposed processes.

During the third stage, the same two groups of educators were asked to formulate full-fledged models, including processes and specific indicators, from the standpoint of:

- Regional digitalization departments (Group 1)
- Regional departments of education (Group 2)

Finally, during the fourth stage, all the experts were pooled into a single group that was asked to make use of the proposals elaborated during the previous three stages to propose a system of processes and indicators describing these processes from the standpoint of independent experts in the field of education.

During the second part of the brainstorming activity (sessions 3 and 4), the experts worked with the indicators of the Sustainable Development Goals in education and their possible correlations with smart school processes.

During the first stage, the educators (again randomly divided into two groups) examined the indicators of the Sustainable Development Goals (SDG 4) and proposed those indicators that, from their point of view, could be used as smart school indicators at the regional level. At the same time, the experts proposed preliminary correlations between the SDG indicators and groups of digital school renewal processes.

During the second stage, the experts studied the specific indicators corresponding to SDG 4 indicators (several indicators can correspond to one SDG 4 indicator) that were selected during the previous stage and clarified the processes to which these indicators could be attributed.

During the third stage, specific SDG indicators were correlated with the digital school renewal framework, and specific smart school indicators were proposed on the basis of this correlation.

The brainstorming sessions produced several groups of indicators that were given to the expert group, which assessed them against the list of smart school indicators.

3. GROUP INTERVIEW WITH EXPERTS ON THE SMART SCHOOL INDICATOR SYSTEM

To highlight the management perspective, a one-hour unstructured group interview with experts was conducted. Four experts with management experience in the education system (at the regional and national levels) participated. Project materials were shown to the experts before the interview. All the experts' ideas were carefully recorded and compared with the list of indicators.

Based on the results of the group interview, several indicators were offered to the expert group as candidates for the list of smart education indicators. The following selection criteria were used:

1. Clear relationship between the indicator and the concept of smart education as a shift from a traditional school system to a personalized system of education in the digital environment.
2. The indicator should not repeat other smart education indicators proposed earlier.
3. The indicator should capture differences in smart education at the country level.

After the two focus groups and the expert group interview were used to promote idea generation, a list of indicators was prepared for further elab-

oration. The involvement of experts with experience at the national and regional levels made it possible to generate and elaborate ideas on measuring the transition to smart education. This helped to structure and develop the list of smart education indicators.

STRUCTURE OF THE LIST OF INDICATORS

As a result, a list of indicators was proposed for evaluating the status of smart education at the national level. The indicators are grouped into five categories:

- Background indicators of the general education system. Indicators in this category measure the capacity of the school education system and serve as a framework for tracking the national context mainly from the perspective of SDG. The background indicators reflect the contextual dimension of smart education. When background indicators are measured at the national level, they can be used to compare the education systems of different states and assess the flexibility of national education systems as a condition conducive to the transition to smart education.
- At the same time, it should be noted that it would be inexpedient to use background indicators on their own for exploring the transition to the smart school – the degree of their significance is assessed by experts as statistically small.
- Governance of smart education at the country level. This category of indicators measures the capacity of smart education governance at the country level.
- Developing the digital educational environment. This group of indicators describes the digital infrastructure of the education system.
- Renewal of the educational process. This group of indicators describes changes in teaching and learning relating to the smart education transition. It measures not only ICT-supported changes in teaching and learning but also the transition to a personalized model of teaching and learning.

- Renewal of school management practices. This group of indicators describes changes in management relating to the smart education transition. It measures not only the effective use of ICT for school management but also transformative changes in school management that are necessary for the successful transition to smart education.

For each indicator the core logical component (input/process/output/outcome/impact) is specified.

Detailed descriptions of indicators in each category are given below.

SMART EDUCATION INDICATORS

The following list of smart education indicators is organized around the main concepts used for gauging the status of smart education.

BACKGROUND INDICATORS OF CHANGE IN THE GENERAL EDUCATION SYSTEM

Indicator label	Indicator	Core logical component	Definition of indicator	Qualitative or quantitative	Possible data source
B01	Capital expenditure as a percentage of total expenditure on public institutions	Input	Capital expenditure includes expenditure for the construction of new schools, the renovation of existing school buildings and major repairs to them. This indicator shows the level of government interest in school infrastructure improvement and development at the country level. A higher value of the indicator corresponds to a higher readiness of the education system to implement the smart school model.	quantitative	UIS annual survey on formal education built upon annual financial reports. The annual financial reports are submitted by high-level executive agencies (ministries of finance, ministries of education, national statistics services).

Indicator label	Indicator	Core logical component	Definition of indicator	Qualitative or quantitative	Possible data source
B02	Percentage of teachers with the minimum required qualifications	Input	The same as SDG Indicator 4.c.1. It is calculated as the percentage of teachers by education level (pre-primary, primary, lower secondary and upper secondary) who have received the minimum organized pre-service and in-service teacher training required for teaching at the relevant level in a given country and during a given academic year. Ideally, the indicator should be calculated separately for public and private institutions. The indicator measures teachers' ability to provide quality teaching and learning at the level required by national education standards. This indicator was chosen due to the fact that it is already used for SDG4 and its evaluation does not entail additional costs. A higher value of the indicator, other things being equal, shows the ability of the teacher community to implement mechanisms that contribute to the development of the smart school.	quantitative	Administrative data from schools and other organized learning centres

Indicator label	Indicator	Core logical component	Definition of indicator	Qualitative or quantitative	Possible data source
B03	Percentage of children under 5 years of age experiencing positive and stimulating home learning environments, both sexes	Input	The same as SDG Indicator 4.2.3. It is calculated as the percentage of children aged 36-59 months who live in a household in which their mother, father or other adult member engage with them in the following types of activities: reading or looking at picture books; telling stories; singing songs; taking children outside the home; playing; and naming, counting and/or drawing. The indicator measures the ability of households to prepare schoolchildren for study in a smart educational environment. A higher value of the indicator, all other things being equal, corresponds to a higher readiness of households for the transition to smart schools at the country level.	quantitative	Results of country-level household surveys submitted to the UIS
B04	International recognition of school digital activities in education	Outcome	Evaluation of the number of schools participating in international events dedicated to smart education issues (less than 10/10-20/21-...) The indicator measures the correspondence of digital activities of educational organizations to global ideas of education quality. Higher levels of the indicator, other things being different, show a higher readiness of educational organizations to implement the principles of the smart school.	qualitative	National context questionnaire

Indicator label	Indicator	Core logical component	Definition of indicator	Qualitative or quantitative	Possible data source
B05	Gross enrolment ratio for tertiary education, both sexes (%)	Impact	The same as SDG Indicator 4.3.2. It is calculated as the total enrolment in tertiary education regardless of age expressed as a percentage of the population in the five-year age group immediately following upper secondary education.	quantitative	Administrative data from schools and universities or household survey data on enrolment; population censuses and surveys for population estimates by year of age (if using administrative data on enrolment); administrative data from ministries of education on the structure of upper secondary education. All the data is submitted to the UIS.
B06	Mean years of schooling	Impact	Average number of completed years of education of a country's population aged 25 years and older, excluding years spent repeating individual grades. The indicator reflects the realization of learning opportunities for students in a smart school. A higher value of the indicator corresponds to a higher readiness of the national school system for the transition to the smart school.	quantitative	Mainly national population censuses; household and/or workforce surveys

Indicator label	Indicator	Core logical component	Definition of indicator	Qualitative or quantitative	Possible data source
B07	Number of years of compulsory education	Input	The same as SDG Indicator 4.1.7: the number of years of primary and secondary education to which children and young people are legally entitled and which are either free from tuition fees or compulsory or both. Most countries have legislation specifying the age and the level of education (typically pre-primary or primary education) at which children should start school. Such legislation usually also specifies either the number of years of education that are guaranteed or the age at which young people may leave education or, in some cases, both. The number of years of primary and secondary education to which children are legally entitled should ideally be equal to the number of grades of primary and secondary education that young people are expected to have completed before being legally eligible to leave school. A higher value of the indicator corresponds to a higher readiness of the national education system for the transition to the smart school.	quantitative	National legislation and formal education standards and norms on access to schooling and, in particular, the legal entitlement or obligation to attend school; administrative data from ministries of education on the structure of the education system
B08	Completion rate	Impact	The same as SDG Indicator 4.1.2. It is calculated as the percentage of the cohort of children or young people aged 3-5 years above the expected age of completion of the last grade of each level of education who have completed that grade.	quantitative	Population censuses and household surveys submitted to the UIS and aggregated according to its methodology

Indicator label	Indicator	Core logical component	Definition of indicator	Qualitative or quantitative	Possible data source
B08			Given that the smart school provides its students with a personalized approach that potentially reduces early school-leaving, this indicator reflects the readiness of the school system for the transition to the smart school. Its three sub-indicators are B08a for primary education programmes, B08b for secondary education programmes and B08c for high school education.		
B09	Number of years of compulsory pre-primary education guaranteed by the law		The same as SDG Indicator 4.1.7: the number of years of primary and secondary education to which children and young people are legally entitled and which are either free from tuition fees or compulsory or both. Most countries have legislation specifying the age and the level of education (typically pre-primary or primary education) at which children should start school. Such legislation usually also specifies either the number of years of education that are guaranteed or the age at which young people may leave education or, in some cases, both. The number of years of primary and secondary education to which children are legally entitled should ideally be equal to the number of grades of primary and secondary education that young people are expected to have completed before being legally eligible to leave school.	quantitative	National legislation and formal education standards and norms on access to schooling and, in particular, the legal entitlement or obligation to attend school; administrative data from ministries of education on the structure of the education system

Indicator label	Indicator	Core logical component	Definition of indicator	Qualitative or quantitative	Possible data source
B09			Given that children who have studied in pre-primary organizations are more likely to be ready for primary school and have better learning outcomes, this indicator measures a key element of the readiness of the education system for the transition to smart education.		
B10	Grant support system for students	Impact	National-level grant programmes are on board to promote the country's technological expertise through learning activities helping children and youth to acquire math and science skills, engineering/design thinking, inquiry skills and programming skills	qualitative	National context questionnaire
B11	Teacher attrition rate		The same as SDG Indicator 4.c.6. It is calculated as the percentage of teachers at a given level of education leaving the profession in a given school year. In the context of smart education, changes in this indicator can be interpreted as measuring the qualitative and systematic changes in the education system. The indicator reflects the resistance of teachers to their current workload. Studies show that, at the stages of digital transformation, the burden on teachers increases, evoking their negative reaction. A higher value of the indicator is evidence of the insufficient implementation of smart school approaches and mechanisms at the country level.	quantitative	Administrative data from schools and human resource records for educational personnel

Indicator label	Indicator	Core logical component	Definition of indicator	Qualitative or quantitative	Possible data source
B12	Reduction of routine workload of teaching staff with the help of ICT	Outcome	This indicator reflects the impact of ICT tools and platforms on the workload of the teaching staff. It is calculated as the percentage of teaching staff with a reduced workload thanks to ICT in the teaching staff population.	quantitative	National context questionnaire

GOVERNANCE OF SMART EDUCATION AT THE COUNTRY LEVEL

Indicator label	Indicator	Core logical component	Definition of indicator	Qualitative or quantitative	Possible data source
GSE01	Educational standards allow the organization of personalized educational tracks for students	Input	This indicator describes the situation with regard to country-level educational standards that set down learning goals defining what students should know and be able to do at each grade level. This indicator reflects the readiness at the country level to implement data-based educational platforms that provide individualized learning plans for students. Educational standards that allow personalized learning components create conditions for the transition to smart education.	qualitative (y/n)	National context questionaire

Indicator label	Indicator	Core logical component	Definition of indicator	Qualitative or quantitative	Possible data source
GSE02	National educational technology policy allows the organization of personalized educational tracks for students	Process	This indicator describes the situation with regard to the national-level plan that shapes the practice of personalized learning in the digital educational environment and sets down the requirements for personalized platforms, services and tools so as to attain learning goals defined in educational standards through the organization of personalized educational tracks	qualitative (y/n)	National context questionnaire
GSE03	Average teacher salary relative to IT professions requiring a comparable level of qualification	Input	Using IT professional salaries as the benchmark, this indicator shows whether the teaching profession is competitive with regard to comparable occupations and qualifications	quantitative	Administrative data from schools and national statistics records
GSE04	Government promotes the transition to smart education	Input	Country-level plan for the transition to smart education has been developed and/or implemented	qualitative	National survey
GSE05a	Promulgation of evidence-based guidelines and standards for health and well-being in the educational digital environment at the country level	Input	Evaluation of the promulgation of evidence-based guidelines and standards for health and well-being in the digital environment at the country level	qualitative	National context questionnaire

Indicator label	Indicator	Core logical component	Definition of indicator	Qualitative or quantitative	Possible data source
GSE05b	Promulgation of evidence-based codes of ethics in the educational digital environment at the country level	Input	Evaluation of the promulgation of evidence-based codes of ethics in the educational digital environment at the country level	qualitative	National context questio-nnaire
GSE05c	Promulgation of evidence-based privacy and security records in the educational digital environ-ment at the country level	Input	Evaluation of the promulgation of evidence-based privacy and security records in the educational digital environment at the country level	qualitative	National context questio-nnaire

TRANSITION TO THE SMART EDUCATION ENVIRONMENT

Indicator label	Indicator	Core logical component	Definition of indicator	Qualitative or quanti-tative	Possible data source
DEE01	Technical saturation of the digital educational environment	Process	The digital educational environment is proliferated at the school level; BYOD and BYOT policies are in place	qualitative	National context questionnaire
DEE02	Updated digital devices in school	Process	Ratio of computers and digital devices purchased over the last 3 years to the total number of computers	quanti-tative	National educational statistics

Indicator label	Indicator	Core logical component	Definition of indicator	Qualitative or quanti-tative	Possible data source
DEE03	Technological readiness of the school to offer personalized student tracks from the perspective of the digital platforms available at the school	Process	Availability of digital platforms for fostering student-centred learning	qualitative	School survey
DEE04	Availability and demand of digital teaching materials at the school level	Process	Availability of high-quality digital teaching materials that meet the needs of teaching staff	qualitative	National context questionnaire
DEE05	Availability of educational resources (libraries) created and distributed by the teachers themselves	Process	Availability of content libraries for educational purposes	qualitative	National context questionnaire
DEE06	Availability of open resources with verified content for teaching and learning	Process	Availability of open educational resources for educational purposes	qualitative	National context questionnaire

Indicator label	Indicator	Core logical component	Definition of indicator	Qualitative or quanti-tative	Possible data source
DEE07	Infrastructural readiness of the school to offer personalized student tracks from the perspective of digital devices available to students	Input	Percentage of all computers and digital devices available to students for learning purposes	quantitative	School survey
DEE08	Internet coverage of schools	Input	Percentage of schools with broadband Internet access	quantitative	National statistics
DEE09	Possibility of using school-owned digital devices, IT infrastructure and platforms outside of school	Process	Percentage of schools in which school-owned devices, IT infrastructure or digital platforms are available outside of school	quantitative	School survey
DEE10	Availability of technical support for households and the school community to help them to use digital technologies for educational purposes	Process	Systematic technical support for households and the school community to help them use digital technologies in learning	qualitative	National context questionnaire

Indicator label	Indicator	Core logical component	Definition of indicator	Qualitative or quanti-tative	Possible data source
RDP01	Availability of core academic subject standards and socio-emotional learning standards at the state level	Input	Availability of benchmarks for instruction and work aimed at promoting the elaboration of student academic and socio-emotional goals	qualitative	National context questionnaire
RDP02	Participation of schools in the pilot implementation of smart school programmes	Output	Percentage of schools participating in the pilot implementation of smart school programmes over the last 3 years	quantitative	National context questionnaire
RDP03	Synchronization of homework for saving time	Output	Reduction in the amount of time students spend on homework	qualitative	National context questionnaire
RDP04	Analysis and use of data (qualitative data, educa-tional results, records, sur-veys, platform logs) by school staff to improve their work	Outcome	Regular use of data by school staff for improving learning outcomes	qualitative (y/n)	National context questionnaire

Indicator label	Indicator	Core logical component	Definition of indicator	Qualitative or quanti-tative	Possible data source
RDP05	Institutional use of student portfolios, including educational outcomes gained through open learning or extracurricular activities	Process	Use of student portfolios for the country-level recognition and accreditation of a wide range of educational outcomes gained through extracurricular activities	qualitative	National context questionnaire
RDP06	Percentage of teaching and learning taking place in the digital environment	Process	Teaching and learning time in the digital educational environment as a percentage of the overall teaching and learning time. Three sub-indicators: RDP07a (primary school), RDP07b (secondary school), RDP07c (high school)	quantitative	National context questionnaire
RDP07	Contribution of the school (education system) to educational results	Output	Qualitative evaluation of the contribution of the school system to final exam grades in comparison with private tutoring, MOOCs and other private supplementary materials	qualitative	National context questionnaire
RDP08	Availability of popular media and other content resources for the exchange of educational experience	Process	Availability of media content promoting the school's transition to smart education created by school staff and disseminated via social networks and professional channels	qualitative	National context questionnaire

Indicator label	Indicator	Core logical component	Definition of indicator	Qualitative or quanti-tative	Possible data source
RDP09	Use of digital portfolios for project-based learning	Process	Percentage of schools that use digital portfolios for project-based learning on a regular basis	quantitative	National context questionnaire
RDP10	Promotion of personalized learning in a smart learning environment	Process	Percentage of students with continually updated personalized learning plans based on their individual interests; personalized learning plans must be driven and planned with the help of learning analytics that are considered to be part of the smart learning environment	quantitative	School survey

TRANSITION TO THE MANAGEMENT OF SMART EDUCATION

Indicator label	Indicator	Core logical component	Definition of indicator	Qualitative or quantitative	Possible data source
RSMP01	Percentage of teachers who have received in-service training in digital technologies over the last 12 months	Process	Percentage of teachers who have received in-service training organized by external institutes and dedicated to the use of digital technologies over the past 12 months	quantitative	Administrative data from schools; school surveys

Indicator label	Indicator	Core logical component	Definition of indicator	Qualitative or quantitative	Possible data source
RSMP02	Availability of mentors/ coaches who help teachers and school staff to design teaching and learning processes according to the strategy of the school of moving toward smart education	Process	Involvement of mentors and coaches in programmes promoting the transition to smart education with precise information about when the school staff can consult them	qualitative	School surveys
RSMP03	Participation of teachers in digital skill development programmes	Process	Percentage of teachers participating in programmes developing didactic digital skills for using resources and tools for smart learning	quantitative	School surveys
RSMP04	Personalized professional development tracks for teachers	Process	Availability of support of personalized professional development for teachers according to their needs and to the strategy of the school with two variables: (1) availability of individual goals and plans and (2) use of AI and digital platforms for tracking individual professional development plans. This indicator reflects in-service opportunities of professional development for the transition to smart education.	qualitative	State-level surveys

Indicator label	Indicator	Core logical component	Definition of indicator	Qualitative or quantitative	Possible data source
RSMP05	Use of school networking for the implementation of innovative educational interschool projects	Process	Availability of country-level projects allowing schools to share best practices in the development of smart education. Such country-level projects for the school network should promote the collaboration of schools.	qualitative	Administrative data from schools
RSMP06	Percentage of schools that are planning to conduct work on elaborating a vision of smart education that would emphasize the preparation of students for the future in a changing world	Process	This indicator measures the status of a shared vision on the transition to smart education in the school community	quantitative	School surveys
RSMP07	Involvement of students and parents in developing the school's vision	Process	This qualitative indicator reflects the involvement of the school community in the development of a shared vision measured by the breadth of participation of parents and students in decision-making at the school level. Real work on the mass collection and regular use of the results of such activities is impossible without the introduction and	qualitative	School surveys

Indicator label	Indicator	Core logical component	Definition of indicator	Qualitative or quantitative	Possible data source
RSMP07			use of digital tools for collecting and analysing information and the implementation of information security control systems, all of which are important elements of a smart school.		
RSMP08	The involvement of the smart school as a whole in school-to-school collaborations with the use of digital technology	Output	Qualitative evaluation of the level of school-to-school collaborations and partnerships. This indicator reflects the involvement of schools in collaboration with other schools, which is usually promoted by the use of digital technologies.	qualitative	National survey
RSMP09	Data-driven school management and growth of school management indicators	Process	Level of systematic use of digital data (from an integrated ecosystem of platforms and tools) for management at the school level	qualitative	School surveys
RSMP10	Involvement of the school staff in data analysis	Process	Percentage of schools in which the school staff (teachers and administrators) works with data analytics in a data-driven school ecosystem. Two sub-indicators: RSMP10a (schools with a data-driven school ecosystem); RSMP10b (schools in which the staff uses data analytics systematically).	quantitative	School surveys

Indicator label	Indicator	Core logical component	Definition of indicator	Qualitative or quantitative	Possible data source
RSMP11	Student participation in school management	Process	Percentage of students participating in school management. While for small groups of students face-to-face group work is normal, the broader involvement of students in school government requires the use of ICT platforms (e-voting systems, wiki, collaborative spaces, etc.) and data collection.	quantitative	School surveys and national statistics

Based on the analytical review and operational definition of smart education, key indicators are identified and proposed that can be used for monitoring and evaluating the status of smart education at the national level. Descriptions of the indicators include their definition, core logical components for smart education, and possible data sources.

Such practical considerations as data availability and the required resources for data collection are taken into account when defining qualitative and quantitative measures for each indicator.

To modify the indicators for use in the national context, one should implement several recommendations. For an education system situated at the very beginning of the transition to smart education, it would be expedient to focus on background indicators and indicators of the governance of smart education and the smart education environment. When the transition toward smart education has already begun at the country level thanks to the implementation of educational policy measures over several years, indicators of smart teaching and learning and the management of smart education are more sensitive to changes at the school level.

There exist three key approaches to the use of smart education indicators depending on the core logical components to which the latter belong:

- Measuring output indicators (RSMP08, RDP02, RDP03, RDP07) in a row shows the progress in the tangible products of smart education implementation.
- Outcome indicators such as B04, B12 and RDP04 help to track and anticipate benefits from smart education implementation at the national level.
- Impact indicators (B05, B06, B08, B10, B11) describe higher-level goals of education system development to which smart education should contribute.

4. INDICES FOR MONITORING AND EVALUATING THE STATUS OF SMART EDUCATION: METHODOLOGY

After preparing a list of indicators through an analytical literature review followed by expert-driven elaboration, a set of indices based on indicators of key changes of the transition toward smart education at the national level is elaborated.

METHODOLOGICAL FRAMEWORK

To summarize the complex, multi-dimensional realities behind smart education and help to elaborate smart education indicators, a composite approach (cf. Nardo et al., 2008) is employed.

The framework of the input-process approach (Zhang et al., 2016) is extended through the actors' approach according to which indices seek to measure and understand the actors of the educational process. Six indices are proposed:

- The right to education index measures the realization of the right to education at the national level through compulsory education. While this index does not directly relate to smart education, it is important for assessing the impact of smart education at the country level. It is assumed that this index has a direct correlation with the level of smart education development and can be used as a benchmark.
- The input index measures the enablers, resources and external conditions that provide and guide the transition to smart education at the national level.
- The process index is a mean that measures the changes taking place during the transition to smart education at the national level and its viability.

- The national level index is a mean that measures the enablers and resources of the transition to smart education at the national level.
- The school level index evaluates the role of the school as an actor in the transition to smart education.
- The teachers index evaluates the role of teachers as actors in the process of the transition to smart education.

Initially, two concepts were proposed for the construction of indices:

The 'Levels' concept refers to the level of the education system. It operates with three elements: infrastructure, processes, and organization management.

The 'Actors' concept takes into account the role of actors in the education system. Four actors are distinguished: national level, school level, students and parents, and teachers.

For the computation and verification of the concepts on empirical data, it was assumed that they are independent.

During the next step, the sensitivity of the indices was examined, and indices were selected for the sub-concepts:

a) Concept 'Levels'. The indices IL (level of infrastructure) and PL (level of processes) were constructed. The index OL (level of management at the level of the organization) was not constructed, as country-level indicators do not allow the construction of a differentiating instrument for this level.

b) Concept 'Actors'. The indices NA (influence of actors at the national level), TA (influence of teachers as actors in the education system), and SA (influence of actors in the educational organization) were constructed. The index S_PA (influence of students and parents) was not constructed insofar as this factor is negligeable at the national level when assessing the proximity to smart education within the framework of the considered concept.

The rationale to group sub-concepts (and indices) around the two aforementioned concepts is that while these indices are assumed to be independent between two groups, after empirical verification it is possible to

use them for actionable steps within the educational policy. After the key actors (national-level system, school-level system, teachers) and objects (smart education infrastructure, processes within the smart education transition) for monitoring, evaluation and policy formation are defined, measures may be incorporated into the educational policy for developing smart education elements for better educational results. It should be noted that the right to education index describes the context of the education system and was proposed independently of the above conceptualization.

GUIDELINES FOR THE IMPLEMENTATION OF MONITORING AND EVALUATION

Several key factors should be considered with regard to the implementation of smart education monitoring and evaluation:

1. There is a group of indicators that are calculated with the help of surveys in schools and at the national level. Given that these kinds of tools are not available in all national education systems, there is a need to develop standard qualitative and quantitative instruments that can support the evaluation of key aspects of smart education.
2. School-level and national-level questionnaires need to be developed, calibrated and validated to ensure that they capture diverse aspects of smart education. Pilot field research should be conducted to ensure the cross-country comparability of results.
3. An infrastructure should be set up for creating, elaborating and implementing a database of smart education indicators. Publicly available data sources, national statistics, SDG indicators, and survey results should be brought together and harmonized to improve index computation.
4. Indicators should be normalized prior to the calculation of indices. An approach to the normalization of indicators is outlined in detail below. It should be noted that the normalization function is dynamic and so must be recalculated each time as yearly data for smart education evaluation becomes available at the national level.

5. For actionable steps in education policy, the calculated indices should be considered from the standpoint of two concepts of smart education policy: the concept of objects of education policy and the concept of actors of education policy. A comparison of indices made in the context of different education systems can help to formulate actions for target audiences participating in the dissemination of smart education.

APPROACH TO THE NORMALIZATION (STANDARDIZATION) OF INDICATORS

To normalize the indicators, the average value of each indicator for a group of countries should be calculated and assigned an indicator of 100 points. The minimum value of each index is zero. Therefore, each indicator can be normalized to the suggested values in order to provide a uniform presentation of index results. This technique helps to identify minimum and maximum values for each indicator. This should be done insofar as non-normalized values of indicators cannot be meaningfully added or subtracted for index calculation purposes (Mazziotta and Pareto, 2021). It should be noted that the use of the average value for normalization makes for better instrument sensitivity in comparison to other options – the final country indicator can be both above 100 (which indicates a high level of development of smart education) and below 100.

For normalization, one needs:

- To identify a sample of countries that will be used to calculate the normalization values (the values of both developed and developing countries should be taken into account).
- To determine the normalization function (a linear function helps to maintain the level of dispersion of calculated indicators, while a logarithmic function increases the sensitivity of the tool for countries that are less advanced in the field of smart education).

The following groups of countries are proposed for consideration by IITE and BNU:

- Community of BRICS countries (Brazil, Russia, India, China, South Africa) – 5 developing countries that pay attention to the development of education.
- Countries that are represented on the UNESCO IITE Governing Board (Canada, UK, France, Norway, Brazil, Malaysia, China, Mauritius, Ghana, Tunisia, Russia) – 11 countries that have a significant contribution to the development of education at the international level.

To choose the normalization function, it is recommended to normalize indicators using both a linear and a logarithmic function during the first wave of the study and to make a decision based on the obtained res

COMPUTING INDICES ACCORDING TO THE METHODOLOGICAL FRAMEWORK

Indices are computed for measuring the transition to smart education at the system level that takes into account the shift from the traditional education system. Six indices were selected: right to education index, infrastructure index, process index, national level index, school level index, teacher index.

Each index is calculated from different indicators depending on the smart education concepts and sub-concepts involved. An unweighted multiplicative aggregation is used as the aggregation scheme. This is done because the sub-indices after the proposed normalization are expressed in different scales (Greco et al., 2019) and because, with the summative weighted aggregation alternative, there is a risk of losing sensitivity when rare phenomena of smart education are considered (Blancas et al., 2013). The decision to use an unweighted scheme was motivated by the fact that it is difficult to assign a proper weighting method prior to empirical data collection.

The formulas for each sub-index were developed as follows. First of all, indicators relating to the same element of smart education were added in sub-indices. Secondly, indicators that were assumed to be directly cor-

relating were multiplied, while negatively correlating sub-indices were divided (each indicator was multiplied by a factor of either +1 or –1 for calculating the indices). For example, in the sub-index A of the index PL_index, the indicators DEE09, RDP09 and RDP10 reflect conditions for personalized learning that might be initiated at either the school or the system level. The indicator RDP02 reflects school activities in smart school implementation programmes initiated at the system level. It was assumed that RDP02 correlates with the transition to personalized learning, and so multiplication was used for constructing the sub-index.

Moreover, multiplicative aggregation allows the use of sub-indices when theoretically related sub-concepts are combined.

Thus, the indices were computed as follows:

- First of all, indicators of items at the school level were computed based on school surveys and administrative data from schools.
- Secondly, indicators of items at the country level were computed based on a state-level survey, a national context questionnaire and a national population census.
- Thirdly, indices were calculated according to proposed formulas.

The indices were not rounded during the computation process. To place indices in statistical tables, the figures should be rounded off to 2 decimal places.

Scales and computations are presented for each index according to the above framework.

1. The **right to education index** is a context index that measures the realization of the right to education at the national level that is achieved through compulsory education. The right to education index is computed according to the formula

$$ER\_index = B06/(B07+B09)$$

The following example considers two national level cases (2020 data).

United Kingdom of Great Britain and Northern Ireland:

$$ER\_index = 13.41/(13+2) = 0.89$$

Mongolia:

$$ER\_index = 9.42/(12+4) = 0.59$$

One may conclude that the realization of the right to education at the national level is less in Mongolia than in the United Kingdom.

The definitions and formulas of the indicators are listed in Annex 1.

2. The infrastructure index measures the enablers that are needed for the transition to smart education at the national level. The infrastructure index is related to the process index, as it concerns the necessary environment for the transition to smart education. Its sub-indices reflect the capacity for school education improvement in comparison with the digital economy sphere, the extensive agenda of teacher qualifications and implications for preschool practices, and the availability of necessary technological environment for smart education.

The infrastructure index is computed according to the formula

$$IL\_index = A*B*C$$

where

Sub-index	Formula	Definition
A	B01+GSE03	Government's capacity to improve school education
B	B02+B03	Development of the educational environment
C	DEE07+DEE08	Quality of the school environment

The definitions and formulas of the indicators are listed in Annex 1.

3. The **process index** measures changes that take place during the transition to smart education at the national level and its viability. It is related to the infrastructure index yet is independent of the group of actor indices. Its sub-indices reflect key aspects of the transition to smart education from the process perspective: the development of educational technologies, teaching and learning in a digital environment, the professional development of teachers for smart education, strategical issues for school development, and data-driven education.

The process index is computed according to the formula

$$PL\_index = A*B*C*D*E$$

where

Sub-index	Formula	Definition
A	(DEE09+RDP09+RDP10)*RDP03	Development of educational technologies
B	RDP07a+RDP06b+RDP06c	Development of teaching and learning in the digital environment
C	RSMP01*RSMP03	Professional development of teachers
D	RSMP06+RSMP07+RSMP09	School development strategy
E	RSMP10a+RSMP10b	Collecting, analysing and updating data

The definitions and formulas of the indicators are listed in Annex 1.

The next three indices are assumed to be interrelated; however, this fact should be assessed at the empirical stage using statistical analysis.

4. The **national level index** represents a mean measure of the enablers and resources of the transition to smart education at the national level. Its sub-indices reflect the ability of national governments to effectuate the transition to smart education in terms of progress on the education front, the capacity to invest into the necessary school facilities for smart education, and the impact of national-level efforts for improving learning efficiency and effectiveness.

The national level index is computed with the formula

$$NA\_Index = A*B*C$$

where

Sub-index	Formula	Definition
A	B05*3/(B08a+B08b+B08c)	Continuation of education after high school
B	B01+DEE02	Attitude toward school modernization
C	(RDP06a+RDP06b+RDP06c)*RDP09/3	Focus on effective teaching and learning

The definitions and formulas of the indicators are listed in Annex 2.

5. The **school level index** is based on the recognition of the school as an actor in the transition to smart education. In this index, the promotion of student autonomy is considered to be a key aspect of personalized learning, while the professional development of teachers is defined mainly through the formation of skills required for ICT-supported teaching in a smart learning environment.

The school level index is computed by the formula

$$SA\_Index = A*B*C*D$$

where

Sub-index	Formula	Definition
A	DEE07+DEE08	Quality of the school environment for smart education
B	RDP02+RSMP09	Vectors of school development toward smart education and data-driven school management
C	DEE09+RDP10+RSMP06	Promotion of student autonomy in a smart learning environment
D	RSMP01*RSMP03	Professional development of teachers for smart education

The definitions and formulas of the indicators are listed in Annex 2.

6. The **teacher index** is based on a recognition of teachers as actors in the process of the transition to smart education. It reflects the capacity and qualifications of teaching staff for providing a smart education.

The teacher index is computed by the formula

$$TA\_Index = A*B$$

where

Sub-index	Formula	Definition
A	(GSE03*RSMP10a)/B11	Capacity of teaching staff for smart education
B	B02+RSMP10b	Teachers' qualifications for teaching and learning in the smart school

The definitions and formulas of the indicators are listed in Annex 2.

CONCLUSION

Smart education offers schools new opportunities and advantages provided by state-of-the-art educational technologies and methods. It has prompted researchers and educators to develop methodologies for monitoring and measuring this complex process of transition. Specialists view smart education as a tool empowering modern schools to achieve better educational results yet caution against the overuse of smart education as a type of 'technical fix' that simply applies digital technologies to education. Instead, one needs to develop a concept of smart education that takes into account the changing roles of actors and educational environments and the growing volume of collected educational data.

The analytical review identified the main concepts, elements and components of smart education for further operationalization. The analysis concentrated on four key ideas: smart education, smart learning, the smart educational environment and the smart school.

Based on the analytical review, four concepts were proposed to describe and define the transition to smart education in the national context. They helped to elaborate indicators of the monitoring and evaluation of smart education.

Studies of different conceptual frameworks and surveys of educational experts were used to propose indicators for monitoring and evaluating the status of smart education at the national level. The descriptions of indicators included their definitions, core logical components for smart education and possible data sources.

The proposed indicators can be used in the national context as well for the comparison of regional situations. Once data becomes available at the regional level, the indicators can be calculated to track variations between regions in the transition from traditional schools to smart schools.

The six indices presented here are based on indicators that characterize the essential processes of smart education development. However, the low level of smart education penetration in many countries may result in these indices having small values. Preliminary calculations show that the same index can differ by a factor of 10 or more for different countries. On the one hand, this confirms the distinctiveness of the indices; on the other, it creates problems with the comparison of values for the purposes of analysis and the elaboration of recommendations.

As it was not envisaged to test instruments on real data within the framework of this project, a conceptual approach was used for constructing indices. In this approach, directly correlating indicators were multiplied while negatively correlating indicators were divided in the index formula (i.e. each indicator was multiplied by either +1 or –1). This approach to calculating the index is acceptable as a first approximation. However, when the proposed indicators and indices are tested on real country data during subsequent stages of work, it will be necessary to estimate real correlation coefficients or to normalize sub-indices during calculations in order to switch to another model for the formation of indices their construction from proposed sub-indices. In particular, after receiving and evaluating the boundary values of the sub-indices, it will be possible to construct it on the basis of sub-indices and aggregate indices.

A clear approach to defining indicators, computing indices, and making actionable policy recommendations will cast the foundations for the use of indicators for monitoring and evaluating smart education. Further empirical evidence will help to adjust index aggregation schemes and introduce weighting. As a part of regular and cyclical monitoring processes, indices and indicators should advise and facilitate decision making on smart education at the national level.

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ANNEX 1. LIST OF INDICATORS FOR THE RIGHT TO EDUCATION, INFRASTRUCTURE AND PROCESS INDICES WITH FORMULAS AND SCALES

Indicators for the right to education index

Indicator label	Indicator	Definition of indicator	Formula/ Scale
B06	Mean years of schooling	Average number of completed years of education among the country's population aged 25 years and above, excluding years spent repeating individual grades	Average number of completed years of education among the country's population aged 25 years and above, excluding years spent repeating individual grades
B07	Number of years of compulsory education	The same as SDG Indicator 4.1.7: the number of years of primary and secondary education to which children and young people are legally entitled and which are either free from tuition fees or compulsory or both. Most countries have legislation specifying the age and the level of education (typically pre-primary or primary education) at which children should start school. Such legislation usually also specifies either the number of years of education that are guaranteed or the age at which young people may leave education or, in some cases, both. The number of years of primary and secondary education to which children are legally entitled should ideally be equal to the number of grades of primary and secondary education that young people are expected to have completed before being legally eligible to leave school.	Number of years of primary and secondary education to which children and young people are legally entitled and which are either free from tuition fees or compulsory or both

Indicator label	Indicator	Definition of indicator	Formula/ Scale
B09	Number of years of compulsory pre-primary education guaranteed by the law	The same as SDG Indicator 4.1.7: the number of years of primary and secondary education to which children and young people are legally entitled and which are either free from tuition fees or compulsory or both. Most countries have legislation specifying the age and the level of education (typically pre-primary or primary education) at which children should start school. Such legislation usually also specifies either the number of years of education that are guaranteed or the age at which young people may leave education or, in some cases, both. The number of years of primary and secondary education to which children are legally entitled should ideally be equal to the number of grades of primary and secondary education that young people are expected to have completed before being legally eligible to leave school.	Number of years of compulsory pre-primary education to which children are legally entitled and which are either free from tuition fees or compulsory or both

Indicators for the infrastructure index

Indicator label	Indicator	Definition of indicator	Formula/ Scale
B01	Capital expenditure as a percentage of total expenditure on public institutions	Capital expenditure includes expenditure for the construction of new schools, the renovation of existing school buildings and major repairs to them. This indicator shows the level of government interest in school infrastructure improvement and development at the country level. A higher value of the indicator corresponds to a higher readiness of the education system to implement the smart school model.	Capital expenditure on education/Total expenditure on public institutions

Indicator label	Indicator	Definition of indicator	Formula/ Scale
B02	Percentage of teachers with the minimum required qualifications	The same as SDG Indicator 4.c.1. It is calculated as the percentage of teachers by education level (pre-primary, primary, lower secondary and upper secondary) who have received the minimum organized pre-service and in-service teacher training required for teaching at the relevant level in a given country and in a given academic year. Ideally, the indicator should be calculated separately for public and private institutions.	B2.a: Number of teachers in the public education system with the minimum required qualifications (UNESCO term)/Number of teachers in the public education system B2.b: Number of teachers in private schools with the minimum required qualifications (UNESCO term)/Number of teachers in private schools
B03	Percentage of children under 5 years of age with positive and stimulating home learning environments, both sexes	The same as SDG Indicator 4.2.3. It is calculated as the percentage of children aged 36-59 months who live in a household in which their mother, father or other adult member engage with them in the following types of activities: reading or looking at picture books; telling stories; singing songs; taking children outside the home; playing; and naming, counting and/or drawing.	Number of children under 5 years of age with positive and stimulating home learning environments, both sexes/Total number of children under 5 years of age, both sexes
GSE03	Average teacher salary relative to IT professions requiring a comparable level of qualification	Using the IT professional salary benchmark, this indicator shows whether the teacher's profession is competitive with other comparative occupations and qualifications	Average teacher salary/ Average IT professional salary benchmark

Indicator label	Indicator	Definition of indicator	Formula/ Scale
DEE07	Technological readiness of the school to offer personalized tracks for students	Percentage of all computers and digital devices available to students for learning purposes	Number of computers and digital devices (computers, laptops and tablets) available to students for learning purposes/Total number of computers and digital devices for learning purposes at the school
DEE08	Internet coverage of schools	Percentage of schools with broadband Internet access	Number of schools with broadband Internet access at education level h during school year t/Number of schools at education level h during school year t

Indicators for the process index

Indicator label	Indicator	Definition of indicator	Formula/ Scale
DEE09	Possibility of using school-owned digital devices, IT infrastructure and platforms outside of school	Percentage of schools in which school-owned devices, IT infrastructure or digital platforms are available outside of school	Number of schools in which school-owned devices, IT infrastructure or digital platforms are available outside of school at education level h during school year t)/Number of schools at education level h during school year t
RDP02	Percentage of schools participating in smart school pilot implementation programmes	Percentage of schools participating in smart school pilot implementation programmes (if any) over the last 3 years	Number of schools participating in smart school pilot implementation programmes (if any) over the last 3 years/Total number of schools

Indicator label	Indicator	Definition of indicator	Formula/ Scale
RDP06	Percentage of teaching and learning in the digital environment	Teaching and learning time in the digital educational environment as a percentage of the total teaching and learning time	Number of lessons in the digital educational environment/Total number of lessons (outside pandemic periods) RDP06.a: primary school RDP06.b: secondary school RDP06.c: high school
RDP09	Use of digital portfolios for implementing project-based learning	This indicator provides an assessment of the use of digital portfolios for project-based learning in schools by measuring the percentage of schools in which digital portfolios are used on a regular basis for project-based learning	Number of schools that introduced more than 5 learning projects over the last 12 months/Total number of schools
RDP10	Promotion of personalized learning	Percentage of students who have continually updated personalized learning plans based on their individual interests	Number of students whose personalized learning plans were updated in the last 12 months/Total number of students
RSMP01	Percentage of teachers who received in-service training on digital technologies over the last 12 months	Percentage of teachers who received in-service training organized by external institutes and dedicated to the use of digital technologies over the past 12 months	Number of teachers who participated in in-service digital skills training programs organized by external institutes over the last 12 months/Total number of teachers

Indicator label	Indicator	Definition of indicator	Formula/ Scale
RSMP03	Participation of teachers in digital skill development programmes	Percentage of teachers participating in training programmes on didactic digital skills for integrating smart learning resources and tools	Number of teachers who participated in any digital skills training programmes over the last 12 months/Total number of teachers
RSMP06	Percentage of schools that are planning to conduct work on elaborating a vision of smart education that would emphasize the preparation of students for a future in a changing world	Existence of a shared vision on smart education development in the school community	Number of schools with a strategy vision document (part of document) relating to the students' future that is less than 1 year old/Total number of schools
RSMP07	Involvement of students and parents in developing the school's vision	Involvement of the school community in the development of a shared vision, evaluated qualitatively	Number of schools in which students and parents are invited to contribute to the development of the school's vision/Total number of schools
RSMP09	Data-driven school management and growth of school management indicators	Level of systematic use of digital data (from an integrated ecosystem of platforms and tools) for management at the school level	Number of schools systematically using digital data (from an integrated ecosystem of platforms and tools) for management/Total number of schools
RSMP10	School staff work with data analysis	Percentage of schools in which school staff works with data analytics in a data-driven school ecosystem	RSMP10.a: Number of schools with a data-driven school ecosystem/Total number of schools RSMP10.b: Number of schools whose staff systematically uses data analytics/Total number of schools

ANNEX 2. LIST OF INDICATORS FOR ACTORS' INDICES WITH FORMULAS AND SCALES

National level indicators

Indicator label	Indicator	Definition of indicator	Formula/Scale
B01	Capital expenditure as a percentage of total expenditure on public institutions	Capital expenditure includes expenditure for the construction of new schools, the renovation of existing school buildings and major repairs to them.	Capital expenditure on education/ Total expenditure on public institutions
B05	Gross enrolment ratio for tertiary education, both sexes (%)	The same as SDG Indicator 4.3.2. It is calculated as the total enrolment in tertiary education regardless of age expressed as a percentage of the population in the five-year age group immediately following upper secondary education.	Percentage of gross enrolment in tertiary education
B08	Completion rate	The same as SDG Indicator 4.1.2. It is calculated as the percentage of the cohort of children or young people aged 3-5 years above the expected age of completion of the last grade of each level of education who have completed that grade.	B8.a: Number of students who were enrolled in a primary education programme N years ago/Number of students who completed a primary education programme (N –- number of years at the primary level) B8.b: Number of students who were enrolled in a secondary education programme N years ago/Number of students completed a secondary education programme (N – number of years at the secondary level). B8.c: Number of students who were enrolled in a high school education programme N years ago/Number of students who completed a high school education programme (N – number of years at the high school level)

Indicator label	Indicator	Definition of indicator	Formula/Scale
DEE02	Updated digital devices in school	Percentage of computers and digital devices purchased over the last 3 years	Number of computers and digital devices (computers, laptops and tablets) purchased over the last 3 years by the school/Total number of computers and digital devices at the school
RDP06	Percentage of teaching and learning in the digital environment	Teaching and learning time in the digital educational environment as a percentage of the overall teaching and learning time	Number of lessons in the digital educational environment/Total number of lessons (outside pandemic periods) RDP06.a: primary school RDP06.b: secondary school RDP06.c: high school
RDP09	Use of digital portfolios for implementing project-based learning	This indicator provides an assessment of the use of digital portfolios for project-based learning in schools by measuring the percentage of schools in which digital portfolios are used on a regular basis for project-based learning	Number of schools that introduced more than 5 learning projects supported by digital portfolios over the last 12 months/Total number of schools

School level indicators

Indicator label	Indicator	Definition of indicator	Formula/ Scale
DEE07	Technological readiness of the school to offer personalized tracks to students	Percentage of all computers and digital devices available to students for learning purposes	Number of computers and digital devices (computers, laptops and tablets) available to students for learning purposes/Total number of computers and digital devices for learning purposes at the school
DEE08	Internet coverage of schools	Percentage of schools with broadband Internet access	Number of schools with broadband Internet access at education level h during school year t)/Number of schools at education level h during school year t

Indicator label	Indicator	Definition of indicator	Formula/ Scale
DEE09	Possibility of using school-owned digital devices, IT infrastructure and platforms outside of school	Percentage of schools in which school-owned devices, IT infrastructure or digital platforms are available outside of school	Number of schools in which school-owned devices, IT infrastructure or digital platforms are available outside of school at education level h during school year t/Number of schools at education level h during school year t
RDP02	Percentage of schools participating in smart school pilot implementation programmes	Percentage of schools participating in smart school pilot implementation programmes (if any) over the last 3 years	Number of schools participating in smart school pilot implementation programmes (if any) over the last 3 years/Total number of schools
RDP10	Promotion of personalized learning	Percentage of students who have continually updated personalized learning plans based on their individual interests	Number of students whose personalized learning plans were updated in the last 12 months/Total number of students
RSMP01	Percentage of teachers who received in-service training in digital technologies over the last 12 months	Percentage of teachers who received in-service training organized by external institutes and dedicated to the use of digital technologies over the past 12 months	Number of teachers who participated in in-service digital skill training programmes organized by external institutes over the last 12 months/Total number of teachers
RSMP03	Participation of teachers in digital skill development programmes	Percentage of teachers participating in a training programme on didactic digital skills for integrating smart learning resources and tools	Number of teachers who participated in any digital skills training programme over the last 12 months/Total number of teachers

Indicator label	Indicator	Definition of indicator	Formula/ Scale
RSMP06	Percentage of schools that are planning to conduct work on elaborating a vision of smart education that would emphasize the preparation of students for a future in a changing world	Existence of a shared vision on smart education development in the school community	Number of schools with a strategy vision document (part of document) relating to the students' future that is less than 1 year old/Total number of schools
RSMP09	Data-driven school management and growth of school management indicators	Level of systematic use of digital data (from an integrated ecosystem of platforms and tools) for management at the school level	Number of schools systematically using digital data (from an integrated ecosystem of platforms and tools) for management/Total number of schools

Teacher indicators

Indicator label	Indicator	Definition of indicator	Formula/ Scale
B02	Percentage of teachers with the minimum required qualifications	The same as SDG Indicator 4.c.1. It is calculated as the percentage of teachers by education level (pre-primary, primary, lower secondary and upper secondary) who have received the minimum organized pre-service and in-service teacher training required for teaching at the relevant level in a given country and in a given academic year. Ideally, the indicator should be calculated separately for public and private institutions.	B2.a: Number of teachers in the public education system with the minimum required qualifications (UNESCO term)/Number of teachers in the public education system B2.b: Number of teachers in private schools with the minimum required qualifications (UNESCO term)/Number of teachers in private schools

B11	Teacher attrition rate	The same as SDG Indicator 4.c.6. It is calculated as the percentage of teachers at a given level of education leaving the profession in a given school year. In the context of smart education, changes in this indicator can be interpreted as measuring the qualitative and systematic changes in the education system.	Number of teachers leaving the profession in a given school year/Total number of teachers
GSE03	Average teacher salary relative to IT professions requiring a comparable level of qualifications	Using the IT professional salary benchmark, this indicator shows how the teacher's profession is competitive with other comparable occupations and qualifications	Average teacher salary/ Average IT professional salary
RSMP10	School staff work with data analysis	Percentage of schools in which school staff work with data analytics in a data-driven school ecosystem	RSMP10.a: Number of schools with a data-driven school ecosystem/Total number of schools RSMP10.b: Number of schools in which the staff systematically uses data analytics/Total number of schools

Scientific electronic edition

ANALYTICAL REPORT ON THE GLOBAL INNOVATIONS AND MONITORING OF THE STATUS OF SMART EDUCATION

Proofreader Daniil Dynin
Desk-top publishing Obraz Mysli

Format 60x84/16. 1,8MB

This work is a co-publication produced by the UNESCO Institute for Information Technologies in Education, Higher School of Economics, and Beijing Normal University within the joint project “Rethinking and Redesigning National Smart Education Strategy" led by Prof. Ronghuai Huang from Beijing Normal University and Director Tao Zhan from UNESCO IITE.

This report aims to refine and expand the core set of smart education indicators for the purposes of tackling a broader range of policy problems relating to education system transformation. It proposes a set of qualitative and quantitative indicators for monitoring and evaluating the status of smart education and an index methodology for providing a clear structure for indicators, computing indices and making actionable policy recommendations.

In terms of its practical implications, this report should serve as a reference and guide for collecting smart education data at the national level and conducting surveys on smart education.