Front. Digit. Educ. 2024, 1(1): 4–25
https://doi.org/10.1007/s44366-024-0018-7

Theoretical Explorations in Digital Education

Toward the Digital Transformation in Education

Andreas Schleicher

Directorate of Education and Skills, OECD, Paris 75016, France

Abstract This article presents a vision of what the digital transformation in education could look like and what some of its benefits and challenges are. It argues that digital technology, including artificial intelligence (AI), could improve the effectiveness and quality of education by personalizing education, by making it more inclusive and equitable, and by improving the cost-efficiency of the sector. A digital transformation of education also comes with risks that must be mitigated.

Keywords artificial intelligence (AI), digital skills, digital ecosystem, digital transformation

1 Introduction

ChatGPT and the likes have reminded us that the kinds of things that are easiest to teach and test are now also easy to digitize and automate. The OECD has been tracking how well systems like ChatGPT fare on global tests like OECD's Survey of Adult Skills (OECD, 2023a). When doing this first in 2016, artificial intelligence (AI) could solve all of the easy tasks in the Survey of Adult Skills at Level 1; but only about 20% of the more complex problem-solving tasks. That was quite similar to the performance of the adult population in OECD countries. However, in 2021, AI beat most humans at every level. And for 2026 AI is likely to solve 8 out of 10 of the most complex tasks at Level 4, while for humans the OECD average will be more like 2 out of 10. So the advent of AI pushes us to think much harder about what makes us human.

These days, algorithms behind social media are sorting us into groups of like-minded individuals. They create virtual bubbles that often amplify our views but leave us insulated from divergent perspectives; they homogenize opinions and polarize our societies. So tomorrow's schools need to help students think for themselves and join others, with empathy, in work and citizenship. They need to help students develop a strong sense of right and wrong, a sensitivity to the claims that others make on us, and a grasp of the limits on individual and collective action. At work, at home and in community, people will need a deep understanding of how others live, in different cultures and traditions, and how others think, whether as scientists or artists.

The growing complexity of modern living, for individuals, communities and societies, means that the solutions to our problems will also be complex: In a structurally imbalanced world, the imperative of reconciling diverse perspectives and interests, in local settings but with often global implications, means we need to become good in handling tensions and dilemmas. Striking a balance between competing demands—equity and freedom, autonomy and community, innovation and continuity, efficiency and democratic process—will rarely lead to an either/or choice or even a single solution. We need to think in a more integrated way that recognizes interconnections, and our capacity to navigate ambiguity has become key.

Creativity in problem-solving requires our capacity to consider the future consequences of our actions, with a sense of responsibility, and with moral and intellectual maturity, so that we can reflect on our actions in the light of experiences and personal and societal goals. The perception and assessment of what is right or wrong, good or bad in a specific situation is about ethics.

The bottom line is, if we want to stay ahead of technological development, we have to find and refine the qualities that are unique to our humanity, and that complement, not compete with, capacities we have created in our computers.

But to transform education at scale, we need not just a radical, alternative vision of what students need to learn for the AI enabled world, but also effective learning environments in which those knowledge, skills, attitudes and values can be developed. This requires a bolder vision to reconfigure the places, the people, the technologies and the relationships to transform education. Our current schools were invented in the industrial age, when the prevailing norms were standardization and compliance, and when it was both effective and efficient to educate

Andreas Schleicher (✉)
E-mail: Andreas.SCHLEICHER@oecd.org

students in batches and to train teachers once for their entire working lives. The curricula that spelled out what students should learn were designed at the top of the pyramid, then translated into instructional material, teacher guides, and learning environments, often through multiple layers of government, until they reached and were implemented by individual teachers in classrooms. This structure, inherited from the industrial model of work, makes changes in a fast-moving world far too slow. The changes in our societies have vastly outpaced the structural capacity of our current education systems to respond.

In the past, schools were technological islands, with technologies are often limited to supporting and conserving existing practices, and students outpacing schools in their adoptions of technologies. Now schools need to use the potential of technologies to liberate learning from past conventions and connect learners in new and powerful ways, with sources of knowledge, with innovative applications, and with one another.

The conventional approach in education is often to break educational content down into manageable bits and pieces, and then to train students how to solve these pieces. But modern societies create value by integrating different fields of knowledge, making connections between ideas that previously seemed unrelated, building bridges between varied ways of thinking and different cultures, and then connecting the dots to create innovative new approaches.

The past was also divided—with teachers and contents divided by subjects, and students separated by expectations of their future career prospects; with schools designed to keep students inside, and the rest of the world outside; with a lack of engagement with families, and a reluctance to partner with other schools. The future needs to be integrated—with an emphasis on the inter-relation of subjects and the integration of students.

In today's schools, students typically learn individually, and at the end of the school year, we certify their individual achievements. But the more interdependent the world becomes, the more we need great collaborators and orchestrators. During the COVID-19 pandemic, we could see how the well-being of countries depended on people's capacities to take collective actions. Schools need to help students learn to be autonomous in their thinking, and develop an identity that is aware of the pluralism of modern living.

Technology can play a major role to achieve this transformation. The most visible benefit of the use of technology in education has been greater personalization. While a student studies mathematics in an AI-enabled learning environment, the computer can now study how the students learn, where they advance and where they get stuck, and where they get interested, and where they get bored, and then make their learning experiences more granular, more adaptive, and more interactive. Digital learning games can make learning fun. Simulations let students do things that are difficult or costly to do in a real world. Why would we expect a student to listen to a teacher explaining the results of a scientific experiment when the student can now do that experiment in a virtual laboratory? Augmented reality super-empowers the real world and is beginning to transform vocational education and training.

We are also seeing big leaps of the use of technology in tests and exams. One of the greatest issues in education created over recent history was to divorce learning from assessment. In ancient times, most learning was through apprenticeship. With learning, feedbacks and appraisals were always closely integrated and highly personalized. During the industrialization of educational experience, learning and assessment were separated. Students were asked to pile up many years of learning, and then toward the end of their programme they were pulled back and asked to reproduce anything they had learned on the basis of shallow exam questions. This kind of assessment also tended to make learning shallow. Nowadays technology gives us the tools to reunite learning and assessment around complex tasks, providing immediate feedback that can help students learn better, teachers teach better, and schools to become more effective.

AI-enabled learning analytics hold perhaps the greatest promise. Teachers can now get a sense in real time of how different students learn differently, and then embrace those differences with differentiated pedagogical support.

And yet, data from PISA show that technology intensity in classrooms is still often negatively related to learning outcomes (OECD, 2023e). That is not necessarily a bad reflection on technology, perhaps more on our capacity to use it effectively. The reality is still often a patchwork of digital solutions. Schools have to rely on proprietary and incompatible partial solutions, and as different schools make different choices, they cannot harness the data to help students learn better and teachers teach better. Perhaps the most important lesson is that digital solutions are unlikely to work unless teachers are at the heart of their design. Where education systems do not engage teachers in the research and design around technology, teachers are often not effective in supporting implementation.

Smart education is not about technology, but about a radical re-imagination of what teaching and learning can be when powered by technology. We need to shift attention from learning technology to learning activity and better integrate individual, team, and class-wide activities with digital environments. The hardware needs to evolve so that devices are more present but less visible and distractive. And we need smart systems that work for all, that have equity not bolted on but at their core. We need to see that AI empowers learners and teachers rather than dis-empowers them.

In all of this, it is important to keep in mind that technology is not a magic power. It is just an amazing accelerator and an incredible amplifier: It will amplify good ideas and good educational practice in the same way it amplifies bad ideas and bad practice.

Technology can help us make education more inclusive by making learning much more accessible and better adaptive to the different needs of learners, but the experience during the pandemic has also shown how technology can amplify almost any form of inequity in education.

Technology can super-empower teachers as designers of innovative learning experiences. Or it can dis-empower them to become slaves of scripted lesson plans or algorithms they no longer understand.

Technology can help reduce bias through better data, but it can also amplify and entrench bias.

Technology can connect people across geographic, linguistic, or cultural boundaries, but it can also sort them into echo-chambers that amplify their own views and insulate them from divergent thinking.

This article examines some of the conditions to leverage technology for the better, which is based on the *OECD Digital Education Outlook 2023: Towards an Effective Digital Education Ecosystem* (OECD, 2023d). After recalling some of the opportunities and challenges of the digital transformation, this article provides an overview of where countries are on the digital transformation journey, arguing that most countries still face the challenge of shaping a digital education ecosystem that provides teachers and students with the appropriate tools to improve their teaching and learning, that can make the data collected by a variety of digital tools reusable to address important educational objectives, and that empowers teachers and students in their educational careers. Many building blocks are still missing for such an ecosystem to be effective: A stronger emphasis on teachers' professional learning, the availability and interoperability of some key digital tools, investment in hardware and connectivity where not of sufficient quality, and the establishment of new types of institutions that help to implement digital strategies—from "support organizations" to "innovation labs" that can create useful resources for education systems and negotiate their responsible use with all stakeholders.

2 Opportunities of Digital Transformation

2.1 | Personalizing Learning and Education

The personalization of education is one of the major potentials of digitization. Personalization does not imply or assume that education is no longer social and collective; and it simply refers to the delivery of education that helps learners individually in their educational journey. While the contexts can be different, the personalization of education and learning is based on the same principles: Capturing and detecting information that is specific to a student or that can be inferred from detections made on "similar" students; using the detected information to make a diagnosis, for example a recommendation; and in some cases, having an intervention based on this diagnosis, usually under the supervision of a human being (Molenaar, 2021). This can be used for instructional decisions when giving study and careers advice, for designing specific educational interventions, etc. What the diagnosis phase requires is usually a large amount of data that allows comparisons to be made between a specific person and others who share some of the same relevant characteristics.

Here are three examples of how digital tools (and mainly AI-based tools) can support personalized learning or education.

In the classroom, AI applications that directly support student learning show early promise with the development of adaptive learning systems, including intelligent tutoring systems. Personalized learning aims to provide all students with the appropriate curriculum or task, and scaffold them to solve specific problems based on a diagnosis of their knowledge and knowledge gaps. Increasingly, this personalization of learning can rely on digital tools, which not only focus on "what" students should practice next, but also take into account how students learn and consider factors such as self-regulation, motivation, and effort (OECD, 2021). These digital learning resources can also be used and remain helpful outside the classroom, for homework, as automated private tutoring or practice solutions, and for lifelong learning. While still too expensive to be present in education, social robots may perform similar tasks in different ways in the future: They can use adaptive learning to tutor students with natural language, but they can also teach or motivate students to learn by playing the role of a peer student (Belpaeme & Tanaka, 2021).

While adaptive learning data is typically collected when learners interact with a specific software, AI in education can provide diagnosis information to teachers and school leaders about their students based on data collected for administrative purposes. Where countries collect standardized assessment data for each student over time, or just teacher-given grades, AI models can gradually infer a development or growth model for students' learning based on their "past trajectory," and a comparison with students sharing similar characteristics. This can give rise to a variety of recommendation tools. In many cases, the collected data is provided back to schools through dashboards so they can interpret it themselves and take action to improve students' performance (if needed). In a few cases, predictive models about individual students' "growth" can be designed, alerting teachers or educators when specific students do not follow the expected path. This may lead to different types of interventions. Early warning systems based on AI algorithms are based on the same model (Bowers, 2021). Although they may use different types of data (e.g. absence patterns), they usually provide schools with an indication that a specific student is "at risk" of dropping out, notably identifying students that school staff do not necessarily suspect to be at risk. Here again, once the diagnosis is made, human beings have to intervene or ignore the recommendation.

A third example relates to students' career planning and educational guidance. Given the complexity and variety of study paths (and possible careers), countries offer careers and study guidance services. They support students to navigate their education system and its different tracks (if any) but also help them to shape their expectations for a transition into the labour market. Some of these services are based on digital platforms with interactive services: They typically propose a personality test to identify students' tastes and preferences to propose a few possible related occupations and services. While this provides some levels of customization, one could imagine that some of this guidance could be personalized further using not only students' preferences but also their observed strengths and interests within the education system—thus providing more individualized advice.

These three cases present different modes of personalization (or individualization) of education but highlight how a digital transformation could make it possible. In all cases, this requires the collection of data not only about the individual about whom the advice is given, but a number of other subjects. This also requires being able to link data and build digital systems that can reuse relevant information for the mentioned purposes.

2.2 | Inclusion and Equity

The digitization of learning tools and resources can expand access to learning and teaching materials, and thus learning opportunities. Educational platforms proposing open educational resources or massive open online courses platforms (e.g., MOOC) are good examples. They allow learners to access learning materials that may be superior to what they can access locally. When provided universally, closed-access resources limited to students enrolled in an education system can also provide students with more learning opportunities. Contrary to textbooks, digital resources can be made accessible at scale on a mere use basis. When provided by the central government, all students within the education system can access the digital resources, and learn under the supervision of their teachers (but also possibly on their own). In the analogical world, this would be equivalent to providing students with all available textbooks and allowing them to choose the ones that work best for them, something that is not feasible under public resource constraints.

Some of the personalization tools mentioned above can have a positive impact on equality. Studies show that adaptive technology (or personalized learning) can reduce the achievement gaps between students with more and less prior academic knowledge. For intelligent tutoring systems to reduce achievement gaps, they have to be more effective with students with more initial difficulties. Evaluated through a randomized control trial, an intervention in the U.S. State of Maine showed that this may become the case (Murphy et al., 2020; Roschelle et al., 2016). Teachers in the intervention schools used an adaptive learning software to provide students with mathematics homework. The system provides feedback to students as they solve mathematics homework problems and automatically prepares reports for teachers about student performance on daily assignments. Teachers received training and coaching on formative assessment. The study found that students in the schools using the software learned more compared with their peers in the control schools, with large effect sizes, and that the impact was greater for students with lower prior mathematics achievement. A reduction of the achievement gap between different groups of students is thus possible.

Just as important, digital technologies can reduce inequity by facilitating the inclusion of students with special needs and by adapting learning to different learning styles. Technology has, for example, made it much easier to support the diagnosis of learning difficulties such as dysgraphia, and remedial digital responses have also been developed. A variety of smart technologies applied to learning solutions also makes it easier for blind or visually impaired students as well as deaf or hard-of-hearing students to access learning materials and easily perform the educational tasks required from other students. AI-enabled speech to text (and vice versa) or automatic subtitles are the most obvious examples. Learning technologies also help address more difficult inclusion issues, for example by supporting the socio-emotional learning of autistic children (Good, 2021).

There are many other ways in which technology can support equity as well as the implementation of countries' policy toward equity. While early warning systems give an example of AI-based recommendations to provide individualized educational services for those at risk of dropping out, many other individualized interventions can contribute to alleviating inequalities. Digitalization makes it easier for countries and jurisdictions to individualize their services and target students with locally identified characteristics. In some countries, it has enabled shifts from school- or neighbourhood-based equity policies to individualized ones.

2.3 | Enhancing the Quality of Teaching

As teaching is key to students' success, and as human educators are key to the wellbeing and holistic education of children in school, digital technology that supports and provides feedback to teachers and other educators offers another opportunity to improve the quality of education. The examples of personalized education presented above provide teachers with suggestions, recommendations for thought about specific students, unless the information is trivial. Perhaps this can make teachers realize that specific students needed more attention, or that they would have been expected to perform better (or not as well) as they do, or that they might be at risk of dropping out. This information derived from past data that are usually not accessible to them, or from a comparison with other students within a system, enables teachers to reflect on their instruction practices and on how to customize them for a given student or class. In some cases, these digital tools not only provide information to teachers, but also make suggestions on teaching and learning resources.

In the same way, as digitalization makes a wider array of digital learning resources available to students, it does so for teachers. Not only can teachers access open educational resources as well as multiple platforms of digital learning resources, they can also have dedicated platforms with digital teaching resources. The variety of resources can help them design their lesson plans, integrating digital elements into them, but also connect with their peer teachers teaching similar classes or subjects. Here again, the non-rival character and near-zero cost of reproduction of digital resources make it easier to provide teachers with more options to find their relevant teaching resources, made available by their government, their local authority, their school, or cultural agencies nationally and internationally.

Finally, while still work in progress and largely absent from OECD schools, classroom analytics may also support teachers to teach more effectively. Instead of taking students as the unit of analysis, classroom analytics focus on the entire classroom and provide teachers with real-time or post-hoc feedback on how to improve or "orchestrate" their teaching. Many applications have already shown how a variety of solutions could support teachers in better using their time in class. For example, by suggesting when it is a good time to shift to the next teaching or learning activity after students were given individual activities, identifying who would require their attention the most, and recommending how they could engage the whole class in collaborative learning activities. While some classroom orchestration solutions are designed to help teachers in real time, they also provide feedback on teachers' professional practice. For example, how much they talk (compared to their students) and to whom or how they divide their time between different types of activities (Dillenbourg, 2021). Both real-time and post-hoc feedback are akin to personal professional learning opportunities for individual teachers in question, and they furthermore contribute to the personalization agenda as their recommendations target the specific teacher who was (digitally) observed rather than a theoretical or general teaching practice. By providing individual teachers with reflective opportunities on their teaching practices and thus professional learning opportunities, digital technology could subsequently contribute to the wellbeing and learning outcomes of students.

2.4 | Improving Efficiency

In many business and government sectors, beyond effectiveness, a major rationale for digitization lies in efficiency. Many countries have embarked on digital government strategies to this effect, notably to make processes more efficient and easier for their users. The OECD has developed recommendations and principles highlighting these different objectives (OECD, 2020).

There are different ways in which digital technology can increase cost efficiency in education. One example lies in student application (and admission) processes for educational institutions. Applications are sometimes undertaken through digital platforms, especially for the transition toward higher education, where a "matching" (or selection) process is often necessary. The implementation of the National Education Information System (NEIS) in Republic of Korea, an e-government system that allows, among other things, for the digital transfer of students' academic records from one school to the other (as well as from school to university) was estimated to have saved 237 million USD a year when a cost-benefit analysis was undertaken in 2010.

A second area where digitization could lead to cost efficiency is the provision of verifiable degrees and other credentials, for example using block-chain technology (Smolenski, 2021). The gradual development of an infrastructure for digital credentials and the adoption of open standards may lead to a different way of certifying and holding degrees, with individuals being able to manage their qualifications themselves.

A third area where cost efficiency is underway is the collection of system-level statistical information. While in the past statistical information often relied on the establishment of statistical panels (of representative samples of individuals or institutions) and often involved multiple handling of the same data, the use of administrative data (when combined with the interoperability of diverse systems) has made it much easier to get statistical information from operational services in almost real time. Essentially, the latter avoids that administrators re-enter the same information several times.

But efficiency is also about how teachers use their time. Digital technology could help free some of teachers' time, allowing them to focus on the most stimulating aspects of their work. An example is formative assessment, or developments in the automated grading of open-ended essays, because grading and designing assessments are time-intensive tasks when done manually. Another example lies in some of the administrative tasks that teachers have to perform that could be supported by computers. By freeing up time for teachers, smart technologies can allow them to dedicate more time to learners who most need their attention, and to focus on their own continuous professional development or on supporting complex aspects of students' learning, including the acquisition of higher-order or of socio-emotional skills.

2.5 | Enhancing Research and Innovation

Digitalization helps to promote another aspect of efficiency and effectiveness: improving policy design and reform based on evidence, research and quick innovation (Agrawala et al., 2018). In a digitalized education sector, the unprecedented amount of collected data allows researchers and governments to undertake research on their education systems in order to achieve their goals.

While digital tools have a practical utility, their development also helps to uncover educational patterns that were not previously visible. They help to better understand education systems, their actors' behaviours, and thus to design better policies and better practical interventions. For example, the research on early warning systems has not only led to predictive tools, it has also enabled researchers to recognise that different profiles of students were at risk of dropping out and that the types of interventions they required were thus different. Bowers and Sprott (2012) showed that the majority of high school dropouts did not match common wisdom about dropout and these students were thus likely "invisible" to many education stakeholders. This is one example among many showing the value of collecting and analysing robust data and having a strong data infrastructure for better policy design.

2.6 | Making Education More Relevant to Modern Times

Regardless of the benefits of personalization and cost-efficiency, a strong argument for the more intensive use of digital tools and resources in education lies in the development of learners' digital skills. This is one of countries' main educational objectives, recognizing that education should reflect and prepare students for modern societies. While in the past, most evaluations of digital technology in education focused almost exclusively on their effects on students' learning outcomes, usually in mathematics or language, the ongoing digital transformation of our societies have shown that this may not be the only rationale for digital education. Even if the use of digital technology did not improve the effectiveness of education compared to its non-digital equivalent, it might still be important to use digital tools to develop students' digital competences: To ensure a better mastery of digital technology, to familiarize them with it, and to help them understand broadly how it works. Many countries have made "digital competences," defined in different ways, a transversal competence (and made "computer science and/or computational thinking" a more important part of their curriculum).

Generative AI is an interesting point in case. While its emergence was considered as disruptive by many and framed in terms of "cheating," it may be an opportunity to prepare students for the modern age. Assuming that in the near future generative AI becomes more prevalent in the labour market and our lives, getting students used to working with it, getting skilled at preparing prompts, knowing what to (and what not to) expect from it, are all just another dimension of developing their digital competences. Moreover, as a productivity tool, it can allow teachers and students to do much more than what would have been possible before: To produce more texts, create and refine images that would have been very time consuming to produce, get help in producing music and songs, etc.

3 Challenges of Digital Transformation

Opportunities usually come with challenges and unknowns, especially when digital technology is new and evolving at a fast pace. Harnessing the promises of a digital transformation requires both awareness and mitigation of those risks, and a careful cost-benefit analysis. While some of the risks are new and specific to digitization, many are not; digital risks need to be compared with the risks of a non-digital education.

3.1 | Digital Divides

Despite the possible benefits of digital tools for equity, the COVID-19 pandemic has exposed inequalities of access to connectivity and digital tools within education systems, and notably the inequalities of access to digital devices and connectivity (Thorn & Vincent-Lancrin, 2021; Vincent-Lancrin, 2022). As long as access to high quality connectivity and to sufficiently recent digital devices is not universal, digitization will present challenges to equality of opportunities and equity. As noted by Fragoso (2023), the availability of appropriate hardware is a necessary condition for a digital transformation of education, and most countries are aware of this and focus on their investments and digital strategies.

A second challenge of digitization lies in the availability of advanced technology within countries. The devolution of responsibility takes different shapes and forms across countries, but regional governments, local governments and schools themselves play a role in choosing digital tools and resources. In addition, depending on the school funding formula, schools located in different parts of a country may have budgets that are significantly different and allow for a very different provision of digital tools and resources to students and teachers. It is, for example, possible that local education authorities in richer neighborhoods provide their schools and students with more and better AI-based tools (e.g., intelligent tutoring systems), and that this increases the achievement gap and inequality of opportunities with students (and teachers) in poorer neighborhoods and schools. The variation in the cost of (and budget spent on) textbooks and other paper learning resources across schools is likely to be smaller. Depending on the effectiveness of digital learning tools compared to textbooks and static learning resources, digitization may lead to more inequalities unless governments address the issue and ensure that there is at least a minimum basis of digital tools and resources available to all schools in their territory, as is for example the case in France (OECD, 2023b).

A third challenge that may correlate with the previous one comes from the inequality in the digital competences of teachers within countries. Even though the COVID-19 pandemic led to a forced use of digital tools in education and has made teachers more familiar with digital teaching and learning resources and tools, there are still widespread variations in teachers' confidence and interest in integrating digital resources in their teaching.

The jury is still out on whether digitization is likely to widen or close the gap between educational outcomes in high- and low-income regions. On the one hand, digitization requires continuous investments in hardware (connectivity and devices), for which access is still a limitation in many countries. It also requires digital teaching and learning tools and resources that are adapted to local contexts and thus a certain level of available expertise within countries. On the other hand, digitization makes knowledge available in countries where people struggle to access recent knowledge, and light models of generative AI that run on a mobile phone with low bandwidth requirements may support teachers and learners around the world, regardless of their countries' income level. Some middle-income countries/jurisdictions have shown that digitization could be used to improve system performance without introducing advanced technology products or services in the classroom. Digitization is an incremental process, and all countries can reap some of its benefits by clearly identifying the purpose and means of using digitization to solve a problem. In Gujarat (India), for example, where absenteeism of both students and teachers was a problem, the digital monitoring of school attendance coupled with the provision of dedicated human resources and services have led to a significant reduction of the problem (Vincent-Lancrin & González-Sancho, 2023a).

3.2 | Performance of Digital Tools

While digital tools hold many promises for more effective education, they do not have perfect performance yet—contrary to calculators, for example. It is possible that some of the most advanced tools will always have their shortcomings, as is the case for human individual and collective intelligence. As they may make mistakes in the advice or recommendations they provide to students, teachers, parents, etc., it is important to understand their limitations and that they are used under the supervision of competent human beings.

For example, while some early warning systems now approach very good predictive power, Bowers (2021) shows that a significant number of them rely on predictors that are no better than a random guess. In the areas of student engagement, D'Mello (2021) points to new approaches that are developed to better measure students' engagement in learning using facial image analysis and other ways but also notes the inaccuracy of many of the measures used in the field of learning engagement. In the area of classroom analytics, Dillenbourg (2021) notes that some solutions manage to identify whether learners are working individually or in groups with a very high level of accuracy (90%) but identifying the type of teaching and learning activity remains more challenging (67% of accuracy). Those are just three examples, showing that accuracy levels can be very high, but are not guaranteed for any AI-powered education application. Despite their impressive natural language generative power, AI text generators also have "hallucinations" and provide erroneous information with perfect syntax.

Most of the time, these shortcomings do not matter because the stakes are low: AI systems make recommendations that may be more or less correct but are checked and can be discarded by a human being. Human beings also make mistakes and give advice that is not worth following. While AI-based digital tools should be able to demonstrate a certain level of performance to be put on the market, some level of mistake is not necessarily a serious problem as long as those have no serious consequences for the users. We are used to all sorts of errors, made by machines and human beings.

For example, an early warning system that makes good predictions 7 or 8 times out of 10 would actually be very useful—assuming it makes visible those signs or patterns of dropout that are not so visible to teachers and school leaders. In the 2 to 3 cases when such a system is wrong, human educators may realize this is a false alert not to be followed and hopefully the interventions put into place will not be harmful to students that are not really at risk. The cost of those mistakes (in terms of inefficiency and annoyance for "false positive" cases) should be compared to the benefits of the system (compared to a uniquely human detection of potential dropout cases).

However, when a system has high stakes for individuals, tolerance for errors should be minimal, and the systems should have very high levels of performance. For example, if early warning systems were not meant to provide support to students to prevent a bad outcome to happen, but led to an intervention that would be extremely costly and risky for students, it would be unethical to rely on a digital tool with imperfect performance (even if humans were also making imperfect decisions).

3.3 | New or Amplified Biases?

Some AI-based digital tools have been shown to perform better for some population groups than for others. While these issues are also a "performance" problem, they relate to equity and are not easily identifiable based on the overall performance of a digital tool or resource: An AI tool may have a good performance for the entire population, but work badly for some minority groups and put them at a serious disadvantage.

Some digital tools are designed to work better for certain groups of the population, as is for example the case with assistive technologies for students with disability or with special needs. The idea is thus not that all digital tools should always perform the same for everyone. The real problem arises when they unintentionally advantage some groups compared to others and amplify rather than reduce societal biases. While human beings have prejudices and are the origin of societal biases, machines built on these biases will replicate them in a systematic, automated way that could amplify their effects compared to human bias.

Some cases of algorithmic bias with extreme consequences are highlighted in (mainly) other sectors than education (e.g., finance, justice) (O'Neil, 2016). While education does not use much automated advice to make final decisions, Baker et al. (2023) shows that educational tools have also been shown to have unintentional differing performance for diverse groups. Should it happen for decisions that matter for eligibility to certain support services, admissions to schools or universities, or disciplinary sanctions, this would be problematic.

3.4 | Privacy and Data Protection

Digitization raises new issues (and costs) related to privacy and data protection. It also raises new possibilities that expose children to access inappropriate interactions or content. New privacy challenges emerge as an increasing amount of data are collected, especially when they can be linked. The challenge is exacerbated as most people post personal information about themselves on the internet, making it easier to re-identify them from a pseudonymized data-set. As technology and service providers collect and manage increasing amounts of information on behalf of schools and education agencies, more and more data shift outside the direct stewardship of education agencies, feeding concerns that personal information about students or teachers could be used inappropriately or lead to privacy breaches. Harm arising from a privacy breach can affect individuals or communities, may be objective or subjective, and can involve economic, legal, psycho-emotional, or reputational injuries. Privacy and data protection has become a major focus of digital education governance, as discussed in the next section of this article.

3.5 | Ethics of AI

The ethics of AI in education (and elsewhere) has become a major policy concern. There are two types of ethical problems raised by digitization. One type is about what algorithms are allowed to do. For example, where people feel discomfort in the monitoring of students' emotional states, directly or indirectly, even if it would help to identify and address cyberbullying or support their learning, regulation is the right option. Regulation should not inhibit finding weaker ways to balance the costs and benefits, for example by mandating data deletion immediately after processing, which would avoid keeping records of emotional states while reaping the benefits of monitoring (assuming it is accurate and contributes to protecting children or improving their learning performance). Recently published guidelines and forthcoming regulation (in the European Union) address this issue by recommending or planning to limit the uses of AI technology.

A second type (enabled by the first) is about the use of AI by human beings. For example, if the identification of students at risk of dropping out from high school leads to their stigmatization or to their expulsion from school, for example as a way for school leaders to preserve their schools' graduation rates, this would be an unethical use of digital tools as it would harm the students that the algorithm identified as requiring support. If classroom analytics designed to support teachers to improve their teaching practice could be used against them as a "performance assessment" tool, this would also be problematic ethically. The ethical challenge in these cases does not stem from the technology affordances, but from how human beings use them. Guardrails about how AI and other advanced technology should be used by humans that is thus crucial to enable its beneficial uses.

3.6 | Social Acceptance

Challenges for a digital transformation of education are partly technical, as mentioned above. However, probably the main overarching challenge is societal. Education policy makers, teachers, parents, and even students, are used to an education standard with very little to no technology. One implication of a digital transformation is that some current practices, which have sometimes taken several decades to become accepted as a fair and normal practice, will be challenged.

An example lies in adaptive assessment. In some countries, parents, teachers, and their representative organizations, as well as students, pushed back against the introduction of adaptive assessments. As an analogy, ophthalmologists diagnose which glasses people should wear with adaptive assessments: With the support of their machine, they ask a series of questions to fine tune their diagnosis and (hopefully) provide the right prescription for lenses. Not every patient gets the same questions as it depends on what and when you start seeing things, seeing them blurry, etc. Adaptive assessments do more or less the same with mathematics or reading: They try to provide more fine-tuned assessments by providing questions and exercises that get closer to what students know and understand. As the current standard for a fair assessment is that all students take and are assessed on the same questions, adaptive assessments were considered unfair by society.

4 Digital Education Ecosystems: Where Do We Stand and What More Could Be Done?

Given the opportunities and challenges laid out before, governments and other stakeholders willing to foster the digitization of their education systems have several tasks at hand. The first is to improve their current digital education ecosystems. This section provides a brief overview of the findings presented in the *OECD Digital Education Outlook 2023* (OECD, 2023d). The next section will consider the second task of governing digital education to address the challenges and enabling the benefits of a digital transformation of education.

Digital education ecosystems are hybrid human-technology systems. They consist of a mix of human competences, hardware and connectivity, and two types of software: digital tools for system and institutional management, and digital resources for teaching, learning, and assessing in the classroom.

Having a robust physical digital infrastructure is a pre-requisite for digital education. High quality connectivity and enough quality devices for students and teachers are a moving target that requires continuous investment. Improving the quality of connectivity in school and in their country as well as the availability of digital devices is a priority for many OECD countries (Fragoso, 2023; Yun, 2023). While these efforts are essential, just providing digital devices and good connectivity will not lead to a digital transformation of education.

Assuming countries' digital hardware is of good quality, policy makers should consider two big questions:

(1) What are the digital tools and resources that could support effective teaching and learning in the classroom and help achieve some of their educational goals (such as making education more inclusive and equitable, making teaching a more attractive profession, and providing a holistic education)?

(2) What digital education ecosystems should they try to build and, in particular, how can they reuse and share collected data so that it helps achieve these policy goals?

Let us imagine a country that would want to reduce high school dropout. They could communicate this policy objective and let education practitioners address it without any technology. Using technology and data collected through their digital infrastructure, they could think of different ways to support those education practitioners (who would still have to act at the end of the day). A first approach is to create digital tools with reporting systems for absences that trigger a human intervention (e.g., some people go to their home to see if they can reengage the students). This is a reactive approach in which technology enables a faster response than before. A second approach, more proactive, is to try to detect the possibility of drop out before it happens (and intervene pre-emptively). This is what early warning systems try to do. What does it take to do so? Typically, countries need to have data about students who dropped out in the past as well as data about their current students—and based on what they collect, they have to figure out how to design strong early warning indicators and then make the relevant data available to teachers and school leaders in real time. A possible challenge in that scenario is that the relevant data to anticipate a dropout risk may be held in different digital systems (e.g., attendance and teacher-given grades in the school system, standardized scores in the national evaluation system, and information about the school or family characteristics in the jurisdictional information system), so that "early warning" is only possible if the relevant data can be accessed, linked, and brought back in a timely manner to the relevant stakeholders dealing with the students at risk of dropping out. A third approach, which can (and often has to) supplement the two first ones, is to commission research using the data collected about dropout to better understand who drops out and under what circumstances. While this helps improve policies and better understand the phenomenon, this typically does not help an individual student in real time.

An important message of this hypothetical story is that administrative systems can serve other educational purposes than the administrative processes for which they are designed if the data they collect are used for these other purposes—and if the human policies to reach these benefits are developed (OECD, 2023f).

4.1 | System- and School-Level Digital Management Tools

The cornerstone of a digital education infrastructure at the system level lies in a longitudinal student information system. Student information systems collect information about the trajectory of each individual student in the systems and thus provide possibilities to make the entire education system benefit from information that is gathered at the national/jurisdictional level. This is an important digital tool to turn data into actionable information for local stakeholders in real time. As of 2024, most OECD countries have established a longitudinal student information system, but they still use it mainly for statistical purposes rather than as a way to provide real-time information to stakeholders. A second best is to have a central student register with unique longitudinal identifiers for students (and possibly teachers). The information gathered will allow for generating research evidence that may inform education policies within countries—but cannot quickly be turned into action for individual students (Vincent-Lancrin & González-Sancho, 2023b).

Current longitudinal information systems can be classified into four types:

- *The reporting and research approach*. The data and reports produced mainly seek to support policy planning and to inform the public. Most student information systems not only fulfil this function but are also limited to it.
- *The e-government approach*. These student information systems are designed to improve the efficiency of administrative processes (e.g., school transfer, school choice, university application, funds allocation to schools). They contain more data and linkage possibilities than other models, but have a weaker focus on functionalities aimed at improving teaching and personalizing education and on reporting learning data to teachers.
- *The school improvement approach*. Putting school improvement at the core of their mission, they can be close to information systems in the reporting and research approach, but typically report data to schools, generally with a visualization tool. They try to provide information at the individual level and with a granularity that makes it usable by teachers (for example, item-level reporting of assessments).
- *The expert system approach*. Inspired by "expert systems" supporting decision-making, they typically provide rapid and granular feedback to teachers, students, and principals, as well as support materials to enhance learning. Beyond mere reporting, they have predictive models and make recommendations, which may be followed or not.

Countries' digital education ecosystem is comprised of many other system- and institution-level digital management tools. Learning management systems are the equivalent of student information systems at the school/institution level: They allow schools to manage and track information about individual students, which classes they attend, with which teachers, and, in some cases, to access digital content for teaching/learning. Ideally, learning management systems should be able to "push" and "receive" data to and from their jurisdictional student information system. While most countries report that most of their schools use such learning management systems, at least at some educational level, about half of them are not interoperable with system-level student information systems and require schools to manually provide information to their public authorities/ministries, and in turn are unable to receive any insight from the data collected at the jurisdictional level (Vincent-Lancrin, 2023).

The *OECD Digital Education Outlook 2023* shows that most countries provide study/career guidance information through digital means, even though few of them provide tools for more personalized enquiries, and that most national evaluations are digitized or in the process of being so. Digitizing actual high-stakes exams for students is a different story, and while some OECD countries are exploring this path, only a few of them have done it (Finland is an example). A few countries have digitized some aspects of the administration of their paper-and-pencil exams as well as their selective admission processes into higher education and sometimes high school (Vidal, 2023a).

Figure 1 provides a picture of the public provision (and use) of digital system- and institution-management level tools, and shows number of countries who publicly provide the following system- and institution-level management tools at national or sub-governmental levels.

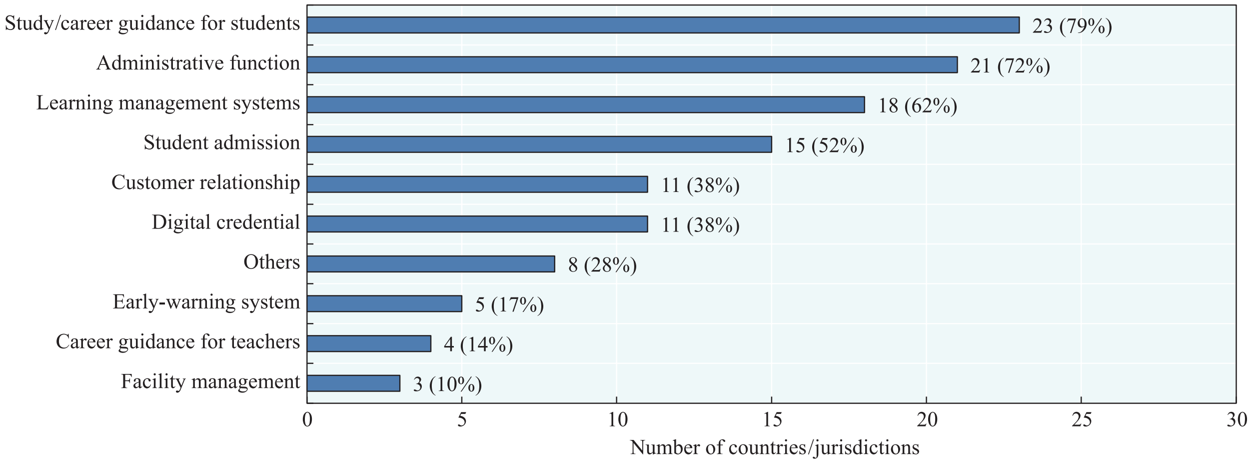

Figure 1 Public Provision of Digital Education Management Tools (2024)
Note. $N = 29$. Nineteen countries/jurisdictions have a central longitudinal student information system, while 3 additional countries have all or most of their sub-governments providing ones. Institution-level management systems are typically provided at sub-governmental level, e.g., states, regions, school districts, and municipalities. See Articles 2 and 3 for more detailed information. All data in the figures of this article are from the *OECD Digital Education Outlook 2023* (OECD, 2023d).

Despite ongoing discussions about AI in education, it is noteworthy that relatively few system- and institution-management digital tools use any AI technology such as learning analytics or recommendation tools. The most advanced uses of technology consist of making information available through dashboards or of implementing rule-based algorithms, apparently for funding mechanisms or for managing enrollments in or applications for schools.

Figure 2 provides the number of countries/jurisdictions who publicly provide digital systems with dashboards or some level of rule-based automated recommendations.

As Figure 2 shown, in education, it is relatively infrequent for digital tools to use even non-AI based algorithms, such as dashboards, or rule-based decision-making or adaptive models. Almost no country reported the use of AI techniques for system-level tools or a common use of them for institution-level tools. There is virtually no "automated" decision- or suggestion-making in education. For example, while most countries have digitized their national standardized evaluations, if not their examinations, almost none use the digital affordances of computer-based testing (such as the use of videos, simulations or adaptive testing). While most countries provide study and career guidance platforms for students, those have relatively little adaptive functionalities that would allow to individualize the study or career suggestions.

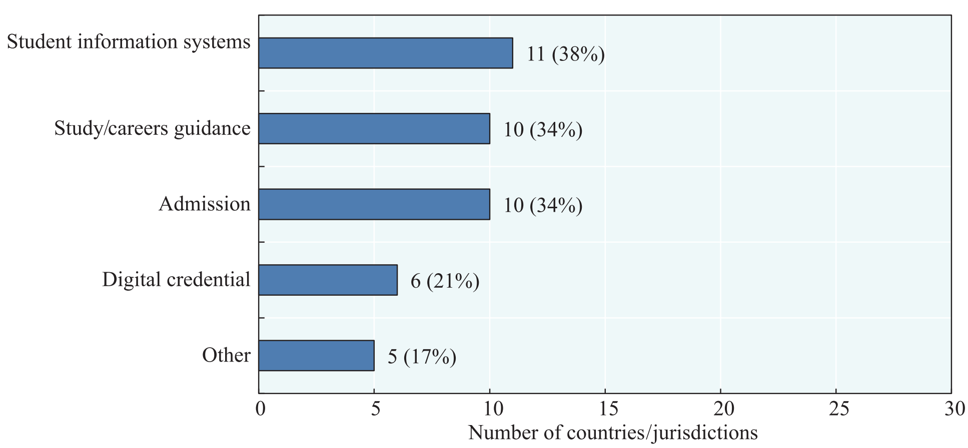

Figure 2 System-Level Management Tools with Automated Rule-Based Displays or Algorithms (2024)
Note. $N = 29$.

4.2 | Digital Ecosystems for Teaching and Learning

A second question is about the digital learning resources that are accessible by teachers and students. This is another issue that the pandemic has made salient and that led to many new promising initiatives within countries. What is the minimum level of digital learning resources that should be available to any student (and teacher) in an education system? Given the new possibilities of digital education, what are the next-generation digital learning resources that would help students succeed?

Let us think again of a country where preventing school dropout is a priority. Beyond the use of data collected at the system level to power early warning systems and trigger interventions, there could be many instructional ways to keep students engaged in school. Some countries and jurisdictions may be tempted to invest in tools that will help students succeed and ensure they can continue to learn or practice while they are out of school. This could be adaptive learning systems for example. They could also be interested in software that help students remain engaged in their learning. They could provide a variety of resources that will help students find what they are interested in and support teachers in developing their students' skills in this area, even if not in mathematics and literacy. They could provide teachers with resources to better understand what is of interest to their students, to design more easily engaging lesson plans, etc. All these would assume that an engaging education in subjects of interest to the students would help keep them in school, especially if they are supported and successful. This is already what teachers do, but digital tools can help them to diversify and individualize their teaching. A country making this assumption may want to have a digital ecosystem with some of the teaching and learning tools and resources mentioned above.

As shown by Figure 3, most countries are now involved in the provision of digital teaching and learning resources for both students and teachers (Yu et al., 2023).

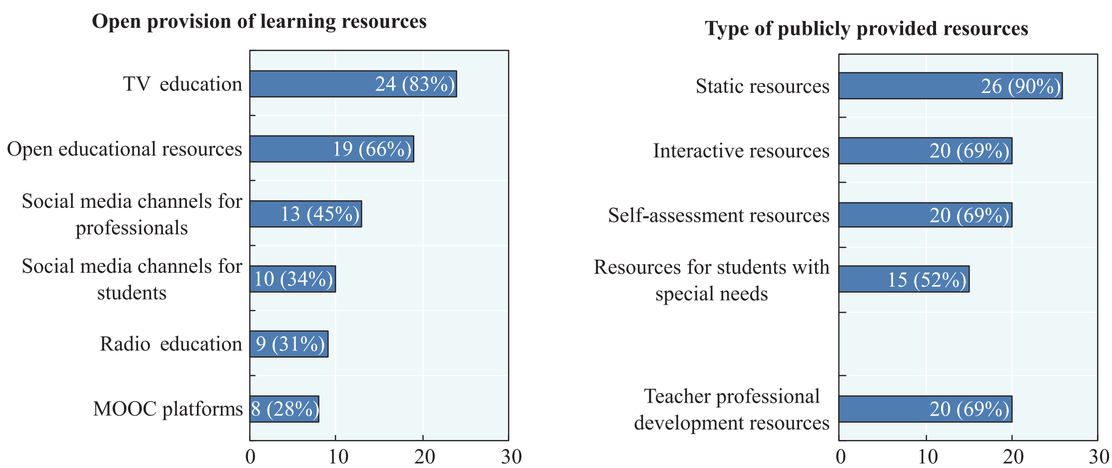

Figure 3 Public Provision of Open and Closed Access Teaching and Learning Resources (2024)

Note. $N = 29$.

The OECD, alongside other international organizations such as UNESCO, have long encouraged countries to develop platforms of open educational resources, such as OERs have the advantage of being available free of charge to everyone and thus can support not only students and teachers, but also the general public and lifelong learning. MOOC platforms have also expanded and offered as the case for TV and radio education and social network channels in selected countries. Most of these offers are boosted by the COVID-19 pandemic and remain available in some countries. Some of these resources are mapped against the national or jurisdictional curriculum. While open educational resources are important, notably to provide an equal baseline to all, the risk is that they get outdated if not continuously updated and modernized. When curated by governmental authorities, one can expect them to be of good quality. In many countries, governmental platforms are supplemented by non-governmental OERs developed by teachers, non-governmental organizations, universities, etc.

Another way for countries to support teachers and students is to license digital learning and teaching resources from commercial education publishers, or to enable municipalities, or to procure their digital learning resources from them with their public budget. In this case, the digital learning resources and tools are provided on a closed access basis, that is, only students and teachers with a recognized role in the education system will be able to access them.

The advantage of a central provision is that central governments have in principle more capacity to quality assure resources, and that the resources will be available for teachers and students in the entire education system, regardless of the preferences of their school leaders or choices of sub-governments. This can be an effective way to level out the playing field, where there is a very uneven provision of digital learning resources and tools. The possible disadvantage of a central provision is that the resources are provided but not used. Schools or local governments may be better placed to choose what suits their students. In any event, while having a baseline of "free of charge" or open resources is important to allow all citizens to benefit from public education, private providers remain overall better placed to keep learning resources up to date and should certainly remain part of the public provision/procurement equation.

As of 2024, the majority of digital learning and teaching resources provided by public authorities and used in the classroom remain static, such as (non-interactive) digital textbooks, video content, and past exam questions, which may often merely transpose conventional chalk-and-board teaching methods to a digital format. Static digital resources are useful and will always keep a key role in the education process, as is the case for physical, non-digital resources. However, the lack of engagement with AI-based digital learning resources may be a missed opportunity to provide more individualized teaching and learning. Most digital learning resources provided and used in OECD schools are non-adaptive. Interactive digital textbooks are the most widely used "advanced" digital learning resources: They are more interactive and include exercises related to the lessons, etc., but they are still typically not adaptive. Intelligent tutoring systems, which could allow students to overcome some of their misconceptions and master procedural knowledge, are still rarely available and used within countries—not to mention other types of smart technology (OECD, 2021). Most AI in education seems to mainly consist of the use of generative AI, a general purpose AI that is used in practice in all countries and jurisdictions, even if not in classrooms (see Figure 4).

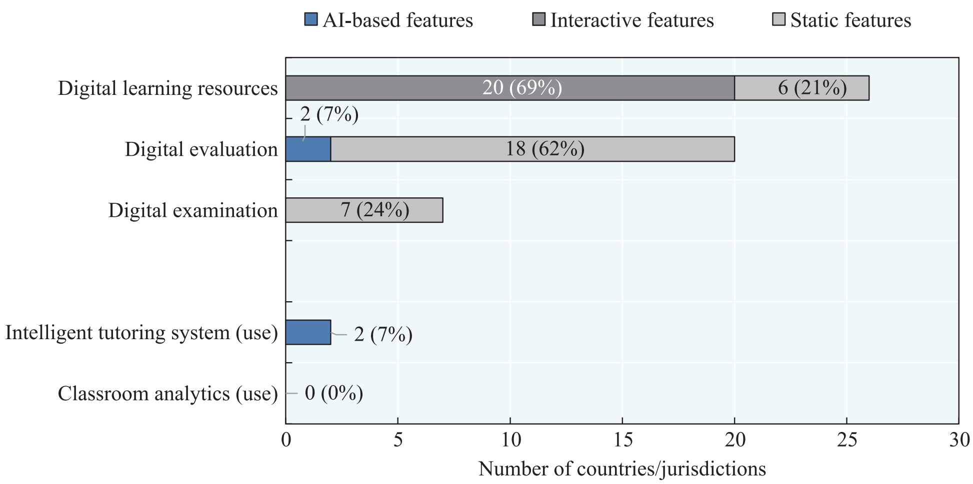

Figure 4 A Limited Provision or Use of Digital Tools and Resources with Interactive or AI-Based Features (2024)
Note. $N = 29$.

How do these digital teaching and learning resources fit in an effective digital ecosystem? Each of these digital tools and resources have a value and function for teaching and learning, and fragmentation is not an necessary issue. It is easier for students and teachers to access those tools and resources without multiplying their access to different platforms, so that being accessible from their school learning management system is an advantage. This is not always possible as students and teachers may have to access them through the platform of a commercial provider (when not provided directly by a public authority). An increasing number of countries offer "single sign-on" solutions to avoid that students manage several access codes (and to protect the privacy of students from the vendors).

As the most advanced digital teaching and learning tools typically collect information about their use by students and teachers, one could imagine that at least some of the data they collect with public funding and often in public schools could be reused and connected to the overall education data ecosystem. It is also possible that the data collected by one digital learning tool could have value for another tool, which would make it valuable for them to be able to exchange information. In what cases this could be useful and how this could be achieved still need to be imagined.

4.3 | Digital Competences

As mentioned above, a strong digital education ecosystem is a hybrid human-machine system and encompasses students and teachers who are able to use the digital tools and resources at their disposal, provide feedback for their further improvement or competently enforce digitization-related regulation. This is also true for school leaders and education administrators as system- and institution-management digital tools get increasingly used. There is no point in providing digital resources that are not effectively used by teachers and students, who should be considered as an integral part of a digital education ecosystem. It is noteworthy that digital competences are just partly about having the skills to use digital devices or find digital resources. These technological competences are important, but digital competences mainly refer to the ability of teachers to use digital tools and resources in their teaching, including advanced technology such as AI. Many countries increasingly emphasize "AI literacy" as an objective for teacher professional learning, which includes both the understanding of the basic functioning of AI models and tools and the use of AI tools (such as specialized educational AI tools or general-purpose tools such as textual or pictural generative AI).

Countries incentive teachers to develop their pedagogical digital competences in different ways. Most countries (24 out of 29) have some national rules or guidelines on teacher digital competences, but significant differences exist across countries: Fourteen countries have rules about pre-service teachers compared to only 3 countries for in-service teachers (the latter are more likely to be devolved to lower levels of government). Most of the rules for pre-service teachers are standards that guide teacher training programmes in designing their programmes: Their enforcement may be checked when accrediting or recognizing those programmes or, more rarely, tested or verified as part of teacher certification/licensing or hiring. Those pre-service standards are often seen as guidelines for in-service teachers, meant to indicate where to put their professional development efforts. As mentioned above, many countries do provide their teachers with digital learning and teaching resources that also encompass the use of digital tools and resources as part of teaching. In general, such rules and guidelines remain high level and as few countries proactively enforce standards by evaluating teachers' digital competences or linking accreditation processes to the development of digital competences, one may wonder how effective they actually are (see Figure 5).

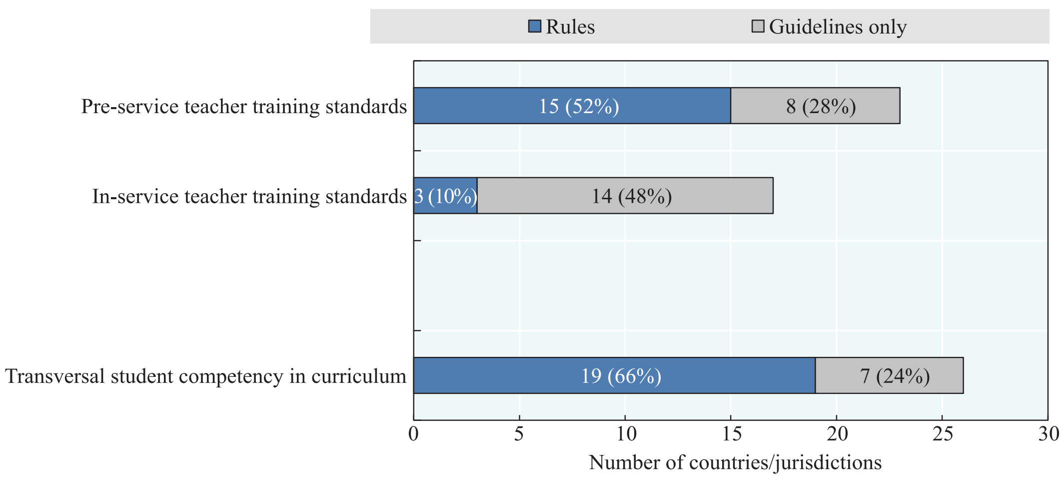

Figure 5 Rules and Incentives for Teachers' Digital Competence Development (2024)

Note. $N = 29$.

In 15 countries out of 29, there are regulatory requirements about digital competences to enter the teaching profession, and in 3 countries to maintain those competences while in service. In 19 countries, teachers are incentivized to develop their digital competences by the integration of digital competences as a transversal competence in the student curriculum.

Almost all countries have national rules and guidelines on developing student digital competences. In most cases, these refer to all educational levels (or all levels excluding VET) and these are often integrated across the curriculum. Expecting students to develop digital competences as part of their mandatory education and across all subjects implies being taught by teachers with their own digital competences. However, very few countries formally assess student digital competences, so the incentive structure is also weak.

Countries and jurisdictions could consider different ways to provide stronger incentives for teachers to develop and maintain their digital competences. They could formally assess teacher digital competences, for example as part of teacher qualification processes (e.g., through examinations), as part of teacher trainee evaluations, as part of compulsory or voluntary certification processes, or by strengthening their relevance as part of internal teacher appraisal or external school evaluation criteria.

Where not already the case, countries and jurisdictions could link their teacher digital competence expectations to concrete accreditation processes of higher education teacher training programmes that could also include criteria on the assessment of digital skills. This could help to ensure relevant content in initial teacher education and promote equal opportunities for students and teachers to develop their digital competences, while still affording higher education institutions (and other teacher training institutions) with flexibility and autonomy.

Building strong incentive structures to encourage participation in relevant professional development activities as part of career advancement paths can be a powerful way to encourage teachers to maintain and (further) develop their digital competences. These might include new reward and mobility structures within the teaching profession that reflect digital skills, including both vertical (i.e., promotion) and horizontal pathways (e.g., specialized digital roles that come with recognized concessions in teaching responsibilities). Formally recognizing digital skills development, for example through certification or micro-credentials, can also incentivize professional development for motivated teachers, although such incentives are unlikely to be effective unless paired with some formal exemption or fulfillment of professional development obligations that matter for career progression and/or compensation (Foster, 2023).

5 Governing the Digital Transformation in Education

Developing a governance of digitalization to shape an effective and equitable digital transformation requires focusing both on how to enable the digital transformation and on how to mitigate its risks and challenges. Innovation or digitalization is not an end in itself. It has to be a means to achieve specific educational objectives: personalization, inclusion of students with disability or special needs, social diversity in school, etc. The first important step is for countries to identify those purposes and how digital technology as well as a robust data infrastructure could help achieve them, if possible. While most countries (23 out of 29 countries) have published a new or updated a former digital education strategy since 2020, most of these strategies are not structured so much around educational objectives and how they can be achieved using digital tools, but more around big topic areas (digital competences, infrastructure, teaching and learning resources, etc.). A digital transformation of education will require countries to identify more specific purposes of digitalization.

Once those are specified, governing digital education includes providing access to a digital ecosystem that allows for these objectives to be achieved, that empowers education actors to use digital tools confidently and competently, where trust about the use of personal data is created thanks to privacy and data protection laws and support for relevant staff, that mitigates digitally-induced inequalities and addresses possible systematic biases, and that creates incentives for education technology (Edtech) developers to continue to develop useful and affordable digital tools and resources for education. Several policy levers can be activated for these purpose: incentives to foster interoperability within the system, setting in place risk-management approaches to privacy and data protection, using public procurement, and creating institutions to facilitate the implementation of digital education policies. Rather than being thought of as addressing one specific issue, they can be used to reinforce incentives and address multiple problems.

5.1 | Interoperability

Interoperability is the capacity to combine and use data from disparate digital tools with ease, coherence and efficiency. It increases the consistency and exchangeability of data collected and maintained by different systems. It reduces the need for ad-hoc processing to re-input, re-format or transform data, so that relevant information can be delivered in a more cost-effective and swift manner to support actions and decisions. In the absence of interoperable digital tools, data linkage and sharing may still be possible but become error prone and time and resource consuming tasks. Interoperability is thus a way to improve efficiency, but also effectiveness of digitalization (Vincent-Lancrin & González-Sancho, 2023c).

Some of the examples of personalization above require that different systems be able to exchange information. For example, it may not be a problem for standardized assessment evaluations to be stored in a different platform than student information—if those systems are able to communicate and share information easily. If not, it is better to have all the information in the same system (typically the system-level student information system).

At a system level, interoperability requires a widespread adoption of shared standards, including technical specifications for technology tools and applications, data definitions and code sets, and general models for system architecture. In some cases, it may also require a greater alignment in organizational processes and a legal framework supporting legitimate and innovative ways of using education data.

The transition from a fragmented to an interoperable educational technology and data ecosystem builds on some important policy dimensions. These include dealing with legacy systems (that is, the fact that at any point of time an ecosystem encompasses technologies developed at different times and using different standards), increasing awareness of the benefits of interoperability, putting in place an effective mix of incentives and mandates for the adoption of standards, ensuring sustainability and capacity to adapt to changing needs, and taking advantage of international initiatives in this area.

The *OECD Digital Education Outlook 2023* highlights many interesting initiatives to enhance interoperability at the country level. It also shows that this is an area where further efforts are needed. While it is difficult to have precise data without a representative school survey, a minority of countries have rules that mandate some interoperability standards (usually with one or more of their system-level administrative systems), or that require some semantic interoperability for digital learning resources. De facto, in less than one third of the reviewed countries do government officials report that most school learning management systems used by schools are interoperable with system-level management systems or other institution-level digital tools. Should a fully effective digital education ecosystem require interoperability, there is still much progress to make.

While regulating technical interoperability is not necessarily a good idea, there are increasingly technical solutions that can facilitate interoperability. Much more can be done by governments on semantic interoperability, both for administrative data and for digital learning resources. About two thirds of countries and jurisdictions recommend the use of some taxonomy for tagging learning resources, but further effort for developing international standards on content (rather than type of resource) could be made.

As Figure 6 shown, the left panel figure shows how many countries use rules or guidelines to encourage different types of interoperability. Ten countries mandate that some systems use specific technical standards (usually to be interoperable with system-level digital systems), while 8 countries encourage it through guidelines. The right panel figure shows countries where school learning management systems are most commonly interoperable with either system-level digital tools or institution-level digital tools.

5.2 | Data Governance

Strong privacy and data protection is another enabler of the digital transformation, both to address objective risks of digital transformation and to create trust in data and AI use in education. Trust in the handling of personal data is necessary to enable the safe and legitimate sharing of data—a necessary condition to harness the opportunities of digitalization. Privacy and data protection is a multifaceted issue. Two dimensions are considered as a given, but they require strong technical competence and infrastructure and human competence and vigilance: Making sure that personal data are protected and not easily hacked (cybersecurity) and making sure that children and students are not exposed to inappropriate content or interactions when using government tools or resources in school (Graafland, 2018; Ronchi & Robinson, 2019).

Many of the major benefits that a digital transformation of education can bring about rely on the promise of more personalized educational experiences

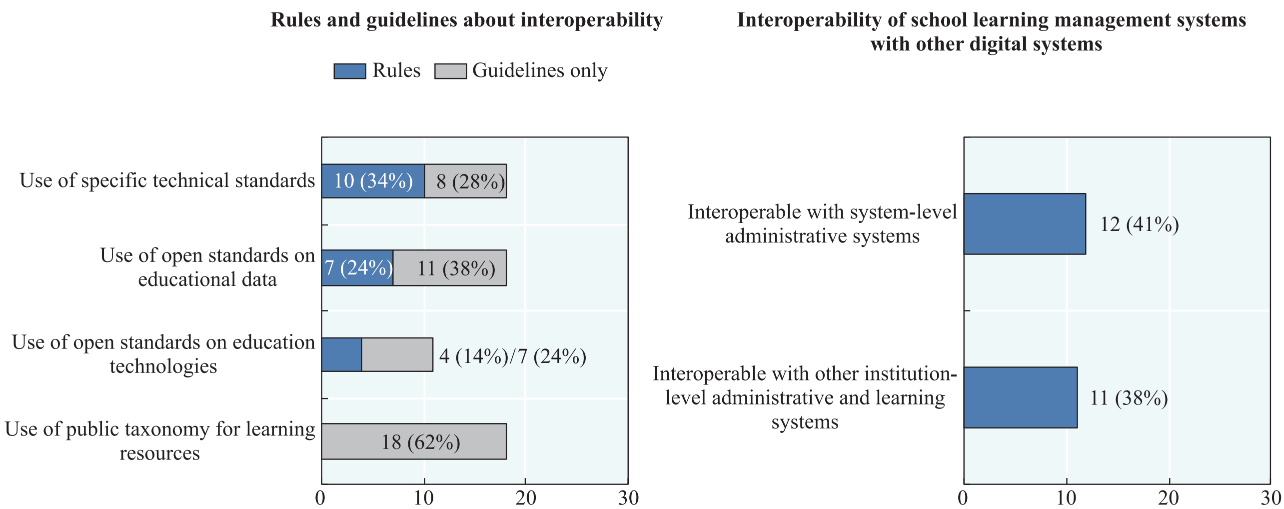

Figure 6 Interoperability within Digital Education Ecosystems: Mandates, Incentives and Reality (2024)
Note. $N = 29$.

and a stronger knowledge base to design education policies and practices. This usually requires using records stored in silos (if they have shared identifiers). While the sharing and linking of personal education records across different technology tools are central to realizing the benefits of digital education, interoperable administrative and instructional systems bring greater privacy and security risks than disparate systems.

Privacy and data protection laws and regulations are essential to prevent privacy breaches and illegitimate uses of personal data. All countries have a privacy and data protection law that applies to education. Most countries that have longitudinal information systems also have specific educational data protection laws or regulations. A risk management framework that recognizes a diversity of uses of personal education data, their potential benefits, and their associated privacy risks is best suited to reconcile legitimate privacy concerns with the benefits of using education data to improve educational outcomes.

An important step in the implementation of such a framework is to break away from the expectation of fully eliminating risk in the use of education data. As long as there is an interest in maintaining some analytical value of the collected data, scenarios with zero privacy risk are unrealistic. Another required change is to shift the focus from privacy controls at the stages of data collection and transformation, to a growing emphasis on controls at the stages of data access, sharing and use. Privacy protection should make use of complementary data-focused and governance-focused strategies: Data-focused strategies consist of treating data prior to their release or sharing, while governance-focused strategies restrain the interactions of custodians and users with the data both by regulating the conditions for data access and use and by increasing awareness and capacity to address privacy risks. While most countries have published guidelines on the enforcement of their privacy and data protection rules, very few proactively monitor their implementation in school. Privacy awareness campaigns and training programmes have been increasingly implemented as ways of strengthening human safeguards for maintaining the confidentiality of personal data. In Europe, for example, the *General Data Protection Regulation* requires national data protection authorities to carry out awareness-raising activities for data controllers, processors and individuals, with a special attention to children (Article 57). Providing privacy and data security training to those can help to build a culture of privacy-respectful data use and enhance trust when data are shared.

More and more commercial service providers collect data about students and teachers in formal education systems. The way they process data is usually restricted by countries' privacy and data regulations, with specific additional restrictions when processing children's data. One aspect that remains largely out of sight of current education policies is the possibility to reuse and share some of the data collected by commercial providers—as is the case for data collected by public educational agencies. Many sectors try to incentivize companies to share some of the data they collect (under data protection laws) to allow for a more vibrant supply of digital tools and resources and more innovation. For example, some of the process information collected by adaptive learning systems might have value for other companies and organizations and allow for the quicker development of new types of digital teaching and learning tools (Vincent-Lancrin & González-Sancho, 2023b).

5.3 | Technology Governance

As advanced technology allows for more automation and systematic impact on human decisions, or for the capture of increasingly sensitive data such as biometric data, the governance of technology itself is becoming a new concern. Technology governance could, for example, consist of setting some obligations when using automated decision-making, forbidding certain types of technology or technology use, requiring the disclosure of the use of automation, requiring that algorithms are explained or that they are "open" and can be examined by experts, etc.

As of 2024, almost no OECD country will regulate technology or algorithms used in education. The only case is France, where algorithms used in public decision-making should be explainable and explained, and where certain technology uses are forbidden under normal conditions. Typically, the educational organizations providing digital tools or resources are responsible for their results, but as of 2024 no country has reported any use of unsupervised automation in education, let alone the use of high stakes decision making. The emergence of generative AI has led to countries publishing a number of guidelines, and two countries have rules pending adoption regarding their use in education (France and Republic of Korea) (Vidal et al., 2023). The European Union is also close to passing an AI Act that will regulate the use of AI tools, making some uses illegal and the use of AI tools in some "high risk" sectors such as education undergo specific processes. Most countries deal with advanced technology with guidelines, and a few countries have published some in the past few years.

One common aspect of those guidelines is the need to keep a "human in the loop." As AI allows for more automated decision-making to happen, this means that while some recommendations or suggestions could be made by AI, human beings should ultimately make the final decision. This is particularly important when AI tools do not have a perfect performance. Most of the time, this is the current situation in education, but the rule can avoid pitfalls. This rule may also mean that a non-digital alternative should be provided, when possible, both for inclusion reasons and to allow the possibility for people to "opt out" (when possible and appropriate) (Vincent-Lancrin & González-Sancho, 2023a).

A second aspect of technology governance lies in the avoidance of algorithmic bias, which is particularly important in education. Algorithmic bias refers to cases where an algorithm advantages (or works better for) some populations compared to others (whether the characteristics relate to gender, race and ethnicity, migration status, etc.). The potential of digital education cannot be fully reached if algorithms that may for example support the personalization of education replicate or even magnify the biases occurring in societies around the world. Research on algorithmic bias focuses on the performance of AI models for different groups of the population. There are other possible forms (and sources) of bias though. Research on algorithmic bias has mainly been undertaken in the U.S. so far, including for algorithms and systems operating outside of the U.S. It has shown the existence of algorithmic bias based on a variety of student characteristics, but the lack of international research limits the understanding of bias. Policy makers should fund research internationally to better identify the various dimensions of bias in different local contexts. Ultimately, they should support the development of tool-kits that would make it cheaper to identify bias. An important take-away is that privacy and data protection should take into consideration the need and importance to collect personal (and sometimes sensitive) data to be capable of detecting (and thus addressing) algorithmic bias and unfair technology. This could be done under a variety of arrangements (Baker et al., 2023).

5.4 | Procurement

Given that education systems in OECD countries are mainly public, public procurement is a very strong lever to incentivize commercial service and product providers to follow certain guidelines or rules. In an OECD country, public procurement in education represented on average 10.7% of all public procurement in 2021, or 1.4% of a country's GDP. This is considerable. While the share of digital tools and resources in educational procurement is unknown, one peculiarity of at least some digital devices or tools is that they can be more expensive than usual education materials such as textbooks and benefit more from an aggregated price negotiating power.

Countries already use public procurement as a policy lever to shape their digital ecosystem and foster data protection and security, interoperability, inclusivity and, to some extent, effectiveness. Some countries could however do it in a more proactive way. Countries use multiple, non-exclusive procurement practices. In most countries, governments play a role in the procurement of digital tools and resources, whether for management or teaching and learning. All countries procure digital system-level management tools. Some countries have a mainly centralized approach to procurement (e.g., Czechia, Hungary, Republic of Korea, Türkiye), while others leave it to schools to purchase most of their digital educational services and resources (e.g., Britain, the Netherlands) or have a mixed approach (e.g., France, New Zealand). Central procurement supports providing equal access conditions across schools in a country/jurisdiction, greater price negotiation power (thanks to economies of scale), and, in principle, the possibility to rely on more technical competences. More decentralized procurement practices may enable schools (or local education authorities) to choose digital tools and resources that meet their specific needs, even though it might entail higher purchase costs.

For companies, decentralized procurement provides less incentives as it requires a larger sales force, makes the procurement process more varied and complex, and allows less possibilities to scale their offer. This makes entering the market more difficult for small firms. At the same time, a centralized procurement process may limit the number of companies and possibilities to enter the market. Mixing different approaches is thus appropriate for governments to balance access and cost-efficiency, and control of the quality of what is bought with public funds against the provision of market incentives for Edtech suppliers.

Without making the final purchase decision, countries and jurisdictions support their schools and sub-governmental authorities in their procurement through different mechanisms (Figure 7). For example, 15 countries negotiate prices with suppliers for some tools; 9 pre-authorise a list of tools and resources to choose from, which gives them the possibility to verify the quality and effectiveness of the resources if they so wish; and 7 countries grant permission on a case-by-case basis, thus allowing for more choice. By attaching product and service criteria to public procurement, governments can help foster a coherent digital ecosystem. As of 2024, 8 countries mandate the public procurement of digital tools and resources according to predefined characteristics: Usually tools must meet specific cybersecurity criteria, and less often, interoperability or ecological (sustainability) criteria (Vidal, 2023b).

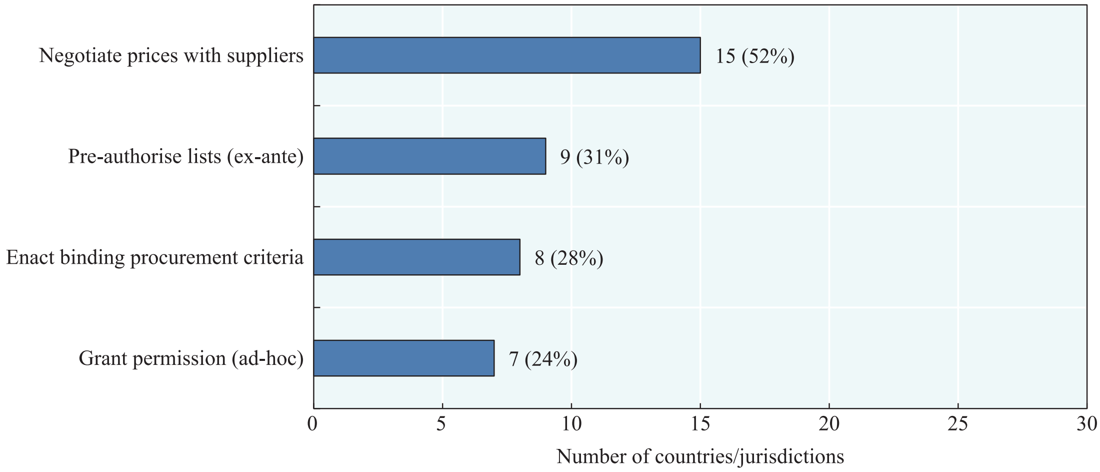

Figure 7 Public Procurement Practices of National or Jurisdictional Governments (2024)
Note. N = 29. Fifteen governments or sub-governments negotiate prices with commercial vendors, 9 of that have a list from which schools or lower public authorities can choose from for their procurement, etc.

Countries could decide to enact more stringent rules for digital education tools to be put on the education market, beyond data protection and cybersecurity standards. They could require tests of effectiveness, the verification of the lack of algorithmic bias, set interoperability requirements with some specific tools, the use of predefined resource taxonomies when appropriate, etc. However, regulation is not always the best option, and they have to also balance these rules against the incentives for commercial providers to develop digital tools and resources. Despite being a large market, education is not always considered a highly profitable one by technology companies, which tend to focus on the education consumer market rather than the formal one.

5.5 | Co-Creation and Multi-Stakeholder Relations

While one challenge for governments is to ensure that commercial providers have enough market incentives to develop quality digital tools and resources for the education sector, another challenge is to ensure the quality, effectiveness, and usefulness of these tools. Traditional education stakeholders usually do not have the competence to develop digital tools for the education sector. Typically, those are developed by for-profit education technology companies, sometimes specifically for the education sector, often by adapting tools that were developed for other sectors to education. It is rare for education ministries to support commercial companies directly, although education technology may benefit from governmental innovation programmes (e.g., for startups or for research and exploratory development). While a few governments support their education technology industries from an international trade perspective, many engage in a dialogue with them by supporting conferences, etc. Education authorities also collaborate relatively rarely with stakeholders such as parents or students when developing or introducing new digital tools and resources.

Acknowledging that education and computer scientists, education technology companies and governments often work in silos, with relatively little involvement of the teaching profession in the definition and development of AI products, new models of research and development of digital technology should be developed. Several models of research and exploratory development are supported by governments that attempt to involve end users more and take an interdisciplinary approach to the development of AI tools and resources in education (Molenaar & Sleegers, 2023). A first approach reflects and adapts a linear approach to innovation: Scientific research is translated and transformed into product development and market applications. An increasing number of initiatives work with end users, although not necessarily from the beginning. A second approach focuses on industry development to help startups to improve products (propositions) with scientific insights and enhance the ecosystem for companies to thrive and scale up. This model resorts to diverse business development activities, from supporting prototype development, optimizing products in multiple schools, diversifying to new sectors in education, through to validating the effectiveness of products to support an evidence-based development of Edtech tools and resources in schools. Other approaches emphasize international collaboration, with similar coordinated projects across countries, or the relationship with teachers and teacher professional development.

For example, the National Education Lab AI (NOLAI) in the Netherlands starts its development process by questions and needs from educational professionals, which are addressed based on scientific insights and recent industry developments. For example, the "Happy Readers" Project started with a request by primary school teachers to be able to better monitor how students' technical reading skills develop over time. Based on what university scholars and industry partners know about reading research and current affordances of technology, such as automated speech recognition algorithms, they developed a new approach to digitally-enhanced reading education.

One of the main purposes of this co-creation would be to develop digital technology tools and resources based on teachers and learners' needs and uses rather than on what is possible given a given state of technology.

5.6 | Monitoring

Finally, while governments sometimes commission research on digital education to their universities or place digital education as a clear priority of their research agenda, it is striking that very few countries actually monitor and evaluate their investments in digital education tools and resources. Information about the physical infrastructure available in schools is missing, not to mention information about uses of digital technology, either as a management tool or as a teaching and learning tool. Nor do countries typically have any research assessing effective versus less effective uses of digital technology at the system, school and classroom levels. It is time for a research effort in this area (OECD-Education International, 2023).

6 Further Steps Toward Digital Transformation

This overview of the findings of the *OECD Digital Education Outlook 2023* shows that countries have made good progress in digitalizing their education systems but that most are embarked on a journey toward a digital transition rather than a digital transformation. Most countries now maintain longitudinal student information systems, but these are mainly limited to producing education statistics. They also use other system-level digital management tools that support their educational processes, such as alert systems to enforce compulsory education, digitalization of exam administration (but not of the exams themselves), digitalization of national evaluations. They also provide or support the provision of digital teaching and learning resources through a variety of platforms or support services for school procurement. And they encourage the use of digital tools and resources by providing direct training and support to education stakeholders by establishing digital competence standards for pre-service teachers and by making students' digital competences as a transversal objective of their curricula.

However, most of them do not take advantage of the possibilities of advanced digital tools. Very few AI-based educational resources are available in classrooms, and in almost all countries, despite not being designed for educational purposes, AI text generators are the only AI tool that is commonly used by students, with or without the blessing of their teachers. Adaptive learning systems, adaptive assessment systems, adaptive study or careers guidance, and early warning systems are absent from most OECD education systems. Regardless of AI-based digital tools, digitalization leads to the collection of a significant amount of data across education systems: While those data tend to move up to the national or jurisdictional level, there is much less effort to make this information actionable and used by teachers, students, families, etc.

So far, the governance of digitalization has mainly focused on avoiding (some of) the possible pitfalls of digital education rather than enabling and unleashing its potential. Countries could take a series of steps to focus on that. Beyond a stronger awareness of the digital education tools and resources that are already available and could be used in their education systems, they should focus on an incremental improvement of their educational processes:

(1) *Identify use cases*. How could digital solutions help achieve some of their education policy objectives? In this article we took the example of preventing high school dropout, but there are many other educational goals that digitalization could help address. What kind of data collection would it take to improve these issues? Are these data already collected somewhere? How could they be brought back in a timely manner to the right end users?

(2) *Improve students information systems or their use*. Countries that have not yet established a longitudinal information system should consider doing so. Those systems are more effective when schools also have learning management systems that can automatically exchange information with system-level digital tools. While this can take several forms, a major avenue for improving their use is to give back the information that is collected at the education system level to practitioners, in a format that can easily inform their decisions and their thinking.

(3) *Develop initiatives to enhance the interoperability of the digital education ecosystem*. A major way to make a digital ecosystem effective and used is to improve interoperability so that data do not have to be re-entered multiple times and that data collected for different administrative and learning purposes can be reused (under usual privacy and data protection regulations). Improving interoperability is difficult as digital technical standards evolve based on research and development rather than administrative will, but it can be done more easily for semantic interoperability. This is

also an incremental enterprise that does not require full interoperability among all digital tools in an ecosystem.

(4) *Use public procurement practices as a policy lever.* Countries already use public procurement in education as a policy lever. However, many procurement practices follow the lines of traditional devolution of responsibilities. While interoperability can be achieved in contexts where responsibility is devolved, it requires more organizational and legal initiatives. Constraints on Edtech providers have to be balanced against the vibrancy of the supply side of the market. Over time, expectations and requirements may increase and procurement could be used to ensure minimal levels of performance of digital tools and resources, the demonstrated absence of bias, and include environmental sustainability criteria.

(5) *Balance different needs when regulating.* While regulation is not always the best solution, it is a powerful lever for governments. For example, regulation about privacy and data protection is important, but it has to be supplemented with training and communication efforts toward staff in schools and administrations, and possibly a more proactive support for its implementation. But it is also important that robust privacy regimes do not become the bedrock of unfairness and discrimination among some population groups by preventing possibilities to identify and address algorithmic bias for example. Regulation regarding procurement and other matters should also be balanced with incentives for the business sector to develop digital tools and resources for the education sector.

Conflict of Interest Andreas Schleicher is a member of the Editorial Advisory Board of *Frontiers of Digital Education*, who was excluded from the peer-review process and all editorial decisions related to the acceptance and publication of this article. Peer-review was handled independently by the other editors to minimise bias.

References

Agrawala, S., Cornago, E., Johnstone, N., Udsholt, T., & Vincent-Lancrin, S. (2018). Using digital technologies to improve the design and enforcement of public policies. *OECD Digital Economy Papers*, (274), 1–39.

Baker, R. S., Hawn, A., & Lee, S. (2023). Algorithmic bias: The state of the situation and policy recommendations. In *OECD digital education outlook 2023: Towards an effective digital education ecosystem*. OECD Publishing.

Belpaeme, T., & Tanaka, F. (2021). Social robots as educators. In *OECD digital education outlook 2021: Pushing the frontiers with artificial intelligence, blockchain and robots*. OECD Publishing.

Bowers, A. J. (2021). Early warning systems and indicators of dropping out of upper secondary school: The emerging role of digital technologies. In *OECD digital education outlook 2021: Pushing the frontiers with artificial intelligence, blockchain and robots.* OECD Publishing.

Bowers, A. J. & Sprott, R. (2012). Examining the multiple trajectories associated with dropping out of high school: A growth mixture model analysis. *The Journal of Educational Research, 105*(3), 176–195.

Cuban, L. (1986). *Teachers and machines: The classroom of technology since 1920*. Teachers College Press.

D'Mello, S. (2021). Improving student engagement in and with digital learning technologies. In *OECD digital education outlook 2021: Pushing the frontiers with artificial intelligence, blockchain and robots*. OECD Publishing.

Dellagnelo, L. (2023). The role of support organisations in implementing digital education policies. In *OECD digital education outlook 2023: Towards an effective digital education ecosystem*. OECD Publishing.

Dillenbourg, P. (2021). Classroom analytics: Zooming out from a pupil to a classroom. In *OECD digital education outlook 2021: Pushing the frontiers with artificial intelligence, blockchain and robots.* OECD Publishing.

Foster, N. (2023). Formalising the development of teacher digital competencies. In *OECD digital education outlook 2023: Towards an effective digital education ecosystem*. OECD Publishing.

Fragoso, T. (2023). Hardware: The provision of connectivity and digital devices. In *OECD digital education outlook 2023: Towards an effective digital education ecosystem*. OECD Publishing.

Good, J. (2021). Serving students with special needs better: How digital technology can help. In *OECD digital education outlook 2021: Pushing the frontiers with artificial intelligence, blockchain and robots*. OECD Publishing.

Graafland, H. J. (2018). New technologies and 21st century children: Recent trends and outcomes. *OECD Education Working Papers*, (179), 1–60.

Molenaar, I. (2021). Personalisation of learning: Towards hybrid human-AI learning technologies. In *OECD digital education outlook 2021: Pushing the frontiers with artificial intelligence, blockchain and robots*. OECD Publishing.

Molenaar, I., & Sleegers, P. (2023). Multi-stakeholder collaboration and co-creation: Towards responsible application of AI in education. In *OECD digital education outlook 2023: Towards an effective digital education ecosystem*. OECD Publishing.

Murphy, R., Roschelle, J., Feng, M., & Mason, C. (2020). Investigating efficacy, moderator, and mediators for an online mathematics homework intervention. *Journal of Research on Educational Effectiveness, 13*(2), 235–270.

O'Neil, C. (2016). *Weapons of math destruction: How Big Data increases inequality and threatens democracy.* Crown Publishing.

OECD. (2020). The OECD digital government policy framework: Six dimensions of a digital government. *OECD Public Governance Policy Papers*, (2), 1–40.

OECD. (2021). *OECD digital education outlook 2021: Pushing the frontiers with artificial intelligence, blockchain and robots*. OECD Publishing.

OECD. (2022). *Education at a glance 2022: OECD indicators*. OECD Publishing.

OECD. (2023a). *Country digital education ecosystem and governance: A companion to digital education outlook 2023*. OECD Publishing.

OECD. (2023b). Human resource policies for digital education. In *Shaping digital education: Enabling factors for quality, equity and efficiency*. OECD Publishing.

OECD. (2023c). *Is education losing the race with technology? AI's progress in math and reading*. OECD Publishing.

OECD. (2023d). *OECD digital education outlook 2023: Towards an effective digital education ecosystem*. OECD Publishing.

OECD. (2023e). *PISA 2022—Insights and interpretations*. OECD Publishing.

OECD. (2023f). *Shaping digital education: Enabling factors for quality, equity and efficiency*. OECD Publishing.

OECD-Education International. (2023). Opportunities, guidelines and guardrails for effective and equitable use of AI in education. In *OECD digital education outlook 2023: Towards an effective digital education ecosystem*. OECD Publishing.

Reich, J. (2020). *Failure to disrupt: Why technology alone can't transform education*. Harvard University Press.

Ronchi, E., & Robinson, L. (2019). Child protection online. In T. Burns, & F. Gottschalk (Eds.), *Educating 21st century children: Emotional well-being in the digital age*. OECD Publishing.

Roschelle, J., Feng, M., Murphy, R., & Mason, C. (2016). Online mathematics homework increases student achievement. *AERA Open*, (4), 1–12.

Smolenski, N. (2021). Blockchain for education: A new credentialing ecosystem. In *OECD digital education outlook 2021: Pushing the frontiers with artificial intelligence, blockchain and robots*. OECD Publishing.

Thorn, W., & Vincent-Lancrin, S. (2021). *Schooling during a pandemic: The experience and outcomes of schoolchildren during the first round of COVID-19 lockdowns*. OECD Publishing.

Vidal, Q. (2023a). Digital assessment. In *OECD digital education outlook 2023: Towards an effective digital education ecosystem*. OECD Publishing.

Vidal, Q. (2023b). Public procurement: Shaping digital education ecosystems. In *OECD digital education outlook 2023: Towards an effective digital education ecosystem*. OECD Publishing.

Vidal, Q., Vincent-Lancrin, S., & Yun, H. (2023). Emerging governance of generative AI in education. In *OECD digital education outlook 2023: Towards an effective digital education ecosystem*. OECD Publishing.

Vincent-Lancrin, S. (2022). *How learning continued during the COVID-19 pandemic: Global lessons from initiatives to support learners and teachers*. OECD Publishing.

Vincent-Lancrin, S. (2023). Learning management systems and other digital tools for system and institutional management. In *OECD digital education outlook 2023: Towards an effective digital education ecosystem*. OECD Publishing.

Vincent-Lancrin, S., & González-Sancho, C. (2023a). Data and technology governance: Fostering trust in the use of data. In *OECD digital education outlook 2023: Towards an effective digital education ecosystem*. OECD Publishing.

Vincent-Lancrin, S., & González-Sancho, C. (2023b). Education and student information systems. In *OECD digital education outlook 2023: Towards an effective digital education ecosystem*. OECD Publishing.

Vincent-Lancrin, S., & González-Sancho, C. (2023c). Interoperability: Unifying and maximising data reuse within digital education ecosystems. In *OECD digital education outlook 2023: Towards an effective digital education ecosystem*. OECD Publishing.

Vincent-Lancrin, S., Urgel, J., Kar, S., & Jacotin, G. (2019). Measuring innovation in education 2019: What has changed in the classroom? In *Educational research and innovation*. OECD Publishing.

Yu, J., Vidal, Q., & Vincent-Lancrin, S. (2023). Digital teaching and learning resources. In *OECD digital education outlook 2023: Towards an effective digital education ecosystem*. OECD Publishing.

Yun, H. (2023). Digital strategies: Providing a common vision for the future. In *OECD digital education outlook 2023: Towards an effective digital education ecosystem*. OECD Publishing.