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Abstract

This article highlights the importance of digitalization as a societal trend for education and discusses how artificial intelligence and learning analytics are transforming (or have the potential to transform) educational practices. It showcases the opportunities of smart technologies for education systems and how the work and role of teachers could be affected, before making some forward-looking concluding remarks.

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Digitalization opens new possibilities for education. While education has always been a sector rich in data, such as grades and administrative information, the use of this data to help students learn better and teachers teach better and to inform decision making in educational administrations is recent. Might digital technology, and, notably, smart technologies based on artificial intelligence, learning analytics, robotics, and others transform education in the same ways they are transforming the rest of society?[1] If so, what might this transformation look like?

There are two important aspects to the "digitalization" discussion in education. A first question relates to how adequately education is responding to emerging societal and labor-market needs. It points to the discussion about curriculum and the increasing importance of skills that are more difficult to automate and that foster innovation, such as creativity, critical thinking, communication, and collaboration.[2] It is also about the acquisition of digital skills by students and teachers not just to adapt to a shifting labor-market demand but also just to understand the times in which we live (and will increasingly live), where smart technology will be pervasive.

A second question about digitalization concerns the changes that technology could induce in the delivery of education, from early childhood to adult learning. This article explores these changes, building on a recent report, *OECD Digital Education Outlook 2021: Pushing the Frontiers with Artificial Intelligence, Blockchain and Robots*, which discusses how digitalization does or could transform education as a sector in the short, medium, and long terms.[3] For example, how do or could the rapid advances in artificial intelligence, learning analytics, robotics, and so on change the ways teachers and students teach and learn? What tasks do teachers perform that computers or robots might take over? Those technological advances can also translate into new work and management processes at the establishment or sector levels, sometimes in quest of cost efficiency and productivity enhancement, sometimes to improve the effectiveness of the sector in reaching its traditional objectives (learning outcomes, equity, completion, etc.). Is digitalization going to change schooling, higher education, or lifelong learning? Will the educational processes be different, with more automated or computer-based tasks throughout the learning process? Will the digital infrastructure available to students, teachers, administrators, and policy makers be different? Will an increased use of computers, data, smart devices, robots (and the technology that powers them) translate into better learning outcomes, more equity, and more efficiency and productivity in education? In short: What are the new possibilities, the opportunities, and the challenges to be expected as the digital transformation affects education? Those questions have become more strategic for education policy makers in the past few years. Between 2015 and 2019, seventeen OECD countries published a digital strategy for education (and sixteen others included a chapter on education in their new national digital strategy).[4]

The rest of this article highlights the opportunities of smart technologies for education systems and points to some possible ways in which they could change teachers' work before making some forward-looking concluding remarks.

Opportunities of Smart Technologies

Smart technologies can improve education systems and education delivery by enhancing access to education, improving its quality for learners, and enhancing its cost efficiency for societies. This section highlights how smart technology contributes (or could contribute) to the achievement of these goals.[5]

Effectiveness

Attending school or university does not always translate into as much academic learning as one would hope. The OECD Programme for International Student Assessment has shown that attending school may actually lead to very different levels of learning outcomes across countries. While no similar evidence yet exists at the level of higher education, one might argue that the same is true at that level, too. One of the key promises of smart technologies is to enhance the effectiveness of teaching and learning for better student learning.

In the classroom, applications that directly support student learning show early promise. Personalized learning aims to provide all students with the appropriate curriculum or task and scaffold them within a task, based on a diagnosis of their knowledge and knowledge gaps. Increasingly, this personalized learning, focusing on the "what," also takes into account how students learn and considers factors such as self-regulation, motivation, and effort.[6] Engagement is key for learning, and solutions that keep students engaged within digital or physical learning environments are being developed to identify their affective states during learning and to nudge them toward re-engagement when they seem to disengage.[7] Social robots perform similar tasks in different ways: they can use adaptive learning to tutor students with natural language, but they can also teach or motivate them to learn by playing the role of peer student. They support teachers by enabling the implementation of different types of teaching and learning strategies.[8] Finally, smart technologies give students with impairments and special needs access to curriculum materials and allow those students to participate in learning activities to an extent that was not possible before, here again increasing the effectiveness of education.[9] In all these instances, smart technologies are usually used in the classroom as tools that support teachers in addressing the needs of their students.

These solutions can be used and remain helpful outside the classroom too, for homework, as automated private tutoring or practice solutions, and for lifelong learning. The largest market for educational technology companies is the consumer market targeting students and parents directly, for recreational learning activities or for tutoring or test preparation.

A second promise of learning effectiveness comes from classroom analytics that support teachers to teach more effectively. Classroom analytics are still a work in progress but many applications already show 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, who would require their attention the most, and how they could engage the whole class in collaborative learning activities. While classroom orchestration solutions can help teachers in real time, they also provide feedback on their own practice, measuring, for example, how much they talk and to whom or how they divide their time between different types of activities.[10] Both real-time and post-hoc feedback are akin to personal professional learning opportunities for the teacher in question and have the significant advantage of being about the specific teacher who was (digitally) observed rather than about theoretical or general teaching practice. In that sense, smart technology has real potential to improve the teaching practice of all individual teachers, and subsequently the learning outcomes of their students.

At the organizational and system levels, smart technologies also hold promise in making education more effective. While their use is still far from systematic,[11] smart technologies can be integrated in most dimensions of school activities, providing administrators, teachers, and learners with feedback to manage school resources as well as to improve the effectiveness of teaching and learning. The rise of a new generation of assessments powered by artificial intelligence (AI) also opens new avenues for recognizing and evaluating competences that were hard to assess with paper-and-pencil tests. This new assessment method could accompany most education systems in their shift to an emphasis on skills (in addition to the traditional emphasis on knowledge). Game-based assessments and simulations allow for more realistic assessments and new ways of assessing skills, such as complex problem solving, creativity, and collaboration.[12] This innovation may support a shift from a teaching method that focuses on specific content knowledge to a teaching method that develops the skills of a discipline at the same time students are learning content.

Finally, the emergence of longitudinal education data systems that follow students throughout their studies also allows for more effective policy and organizational interventions and a better design of educational offerings.[13] For example, in the United States, an analysis of community- college graduation rates, the success of their student-placement strategies in "remedial courses," and students' study patterns as part-time or full-time enrollment led to a reconsideration of what the educational experience of community college students actually is and to a "redesigning" of community colleges.[14] As in other sectors,[15] the use of data supports policy design and interventions.

Equity

Smart technologies can help education systems provide more equitable learning opportunities. In this respect, however, smart technologies are more ambivalent. On one hand, they have the potential to reduce inequity by increasing access to learning opportunities for all and improving learning effectiveness for those who need it the most. On the other hand, without a widespread and equitable availability of smart technologies, inequity could persist or even increase. They may also leave achievement gaps unchanged or even widened, depending on their differential impact on different learners.

Let us start with the difficulties. There are at least two reasons technology may have a negative effect on equity. The first, most obvious reason is the difference in access to devices and connectivity among students from different groups, with students from lower socioeconomic backgrounds at a disadvantage. These students may not have the devices, the connectivity, or the resources that allow them to access and use smart technologies either at the school they attend or at home. These variations across households were clearly exposed during the COVID-19 pandemic and the resulting school closures, during which even in high-income countries a sizeable minority of households lacked devices or connectivity.[16] The same can be said for schools: students attending more affluent schools may afford the smart technologies while students attending poorer schools may be deprived of them. This difference between students with access to smart technologies and those with no access can be exacerbated by the differences among schools in the level of the digital support their teachers and administrators receive. A second reason is that, if technology (e.g., personalized learning) works the same way for everyone, those who start with stronger prior knowledge can maintain their advantage or even make faster progress than those with less prior knowledge. Thus, though technology can support students with less prior knowledge, it could help more advanced students more. This difference would widen rather than reduce the achievement gap.

Despite these challenges, there are also many reasons to believe that smart technologies can advance the equity agenda. First, learning technology can expand access to learning opportunities. Educational platforms proposing open educational resources[17] or massive open online course (MOOC) platforms are good examples. At least in some parts of the world, they allow learners to access learning materials that may be superior to what they can access locally. While many studies have shown that this increased access has not decreased inequity at scale because of the low take-up and the fact that most users are already well educated, a recent systematic review of their effect on equity provides a more optimistic perspective, notably for non-English MOOCs or open educational resources.[18]

As important, smart 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 enabling speech to text (and vice versa) or automatic subtitles are the most obvious examples. Learning technologies also tackle more difficult issues and support the socioemotional (and thus the subsequent academic) learning of autistic children. These technologies increasingly propose ways to help children with attention deficit hyperactivity disorder (ADHD) to self-regulate and better benefit from their schooling. One caveat here is that inclusion is not just about the individual's "fitting in"; it also means that society must be more inclusive and open to differences.[19] Technology encourages that greater acceptance by enabling students with special needs to study in a traditional (and inclusive) learning environment, which also changes peoples' views on disability and special needs. Thus, smart technologies could support efforts by teachers to more smoothly integrate students with special needs in their classrooms.

Second, solutions such as early warning systems are focused on reducing inequity by helping students at risk of dropping out from high school (or university) to graduate—students who drop out typically come from disadvantaged and minority backgrounds. Early warning systems also help educators design appropriate interventions by identifying the factors or indicators most likely to predict dropout.[20] Some use of learning analytics within institutions, for example, to monitor student engagement or redesign study programs, could have the same effects, should the educational institution pay particular attention to inequity.[21] The diagnosis has to be followed up by some human intervention that could help teachers and administrators develop appropriate solutions for those students at risk.

Third, the use of learning analytics as exemplified by personalization at the individual level, be it using intelligent tutoring systems or learning analytics to keep students engaged in learning, all hold promise in reducing inequity, notably by supporting students with less prior knowledge to learn at the right pace. Box 1 describes an online intervention that reduced the learning gap between the strongest and weakest students in mathematics at the beginning of the intervention. There is little evidence, however, that adaptive learning *generally* reduces achievement gaps between students. Adaptive learning technology can also help students practice and make progress at home, outside of the classroom, supported by intelligent tutoring systems. It may be important for students from households where parents can support their students less effectively with their school work, directly or indirectly.

Classroom analytics can also give feedback to teachers about how they could improve their teaching; specifically how and when to pay more attention to different groups of students in their class, based on their academic level, gender, ethnicity, and so on.

Box 1. Personalization in Math Homework Can Help Reduce the Achievement Gap: A U.S. Study

Few studies show that adaptive technology (or personalized learning) reduces the achievement gap between students with more and less prior academic knowledge. And yet, in order for intelligent tutoring systems to reduce achievement gaps, they would indeed have to be more effective with more initial difficulties. Evaluated through a randomized control trial, an intervention in the US state of Maine showed that this may become the case.[a] Teachers in the intervention were asked to use ASSISTments 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 that were assigned to ASSISTments 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. The evaluation confirms initial results by Roschelle and colleagues, which found evidence of strong math learning outcomes and a reduction of the achievement gap when the platform was used.[b]

[a] Robert Murphy, Jeremy Roschelle, Mingyu Feng, and Craig A. Mason, "Investigating Efficacy, Moderator, and Mediators for an Online Mathematics Homework Intervention," *Journal of Research on Educational Effectiveness* 13, no. 2 (2020): 235–270, available at https://doi.org/10.1080/19345747.2019.1710885.
[b] Jeremy Roschelle, Mingyu Feng, Robert Murphy, and Craig A. Mason, "Online Mathematics Homework Increases Student Achievement," *AERA Open* 2, no. 4 (2016): 233285841667396, https://doi.org/10.1177/2332858416673968.

Efficiency

In most sectors other than education, smart technologies are used to enhance the cost efficiency of operations by automating a number of tasks and processes, making services faster and often less expensive.[22] While education might be behind most other sectors in this respect, digitalization is also making many educational processes more efficient as interactions between stakeholders and educational institutions become increasingly automated. As noted earlier, in teaching and learning, some degree of automation is gaining ground. To what extent will digitalization allow for enhanced cost efficiency and productivity in education?

Any discussion of cost efficiency should keep in mind that technology incurs investment and maintenance costs, which must be compared with the costs of current arrangements. Digital technology has not always delivered on its cost-efficiency promises in the past because, as is sometimes forgotten, beyond the initial investment, it must be continuously upgraded, maintained, and so on. Some environmental considerations may also be factored in.

Nevertheless, as in other sectors, there are good reasons to believe that smart technologies could increase cost efficiency in education. One example lies in the application (and admission) process for educational institutions. Applications are increasingly undertaken through digital platforms, especially in higher education, where a "matching" (or selection) process is often necessary. In open-admission institutions, when no selection is required, implementing seamless automated processes is even easier. The implementation of the National Education Information System (NEIS) in 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 USD 237 million a year in 2010.[23]

A second area where digitalization could lead to cost efficiency is the provision of verifiable degrees and other credentials on blockchain. The gradual development of an infrastructure for digital credentials and the adoption of open standards will 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 under way 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 handlings of the same data, the use of administrative data combined with the interoperability of diverse systems has made it much easier to get statistical information from operational services in almost real time.[24]

But efficiency is also about how teachers use their time, and smart technologies can free some of their time and allow them to focus on the most stimulating aspects of their work. An obvious example is formative assessment or developments in the automated grading of open-ended essays because grading and making assessments are time-intensive tasks when done manually. Another example is the diagnosis of special needs, which can now be supported by technology solutions. By freeing up time for teachers, smart technologies can allow them to give more time to learners who most need their attention and to focus on complex aspects of learning, including the acquisition of higher-order or socioemotional skills, or on their continuous professional development.

The evidence shows that a cost-benefit analysis comparing the benefits of smart technology, including the nonfinancial ones mentioned earlier, to that of an existing solution will determine how cost-efficient it is for a given service (or educational goal).

The Future of Teaching

The emergence of smart education technologies or solutions powered by AI, learning analytics, and algorithms and other technologies presents many opportunities. As mentioned in the previous section, they supplement and support teachers, allowing them to become more equitable and inclusive and more effective in helping their students learn and also possibly allowing them to benefit from gains in efficiency at the system (or classroom) level.

At the same time, they raise a number of questions. How can societies best harness the benefits of technology in education while limiting its possible risks? This challenge involves a good understanding of the opportunities and risks, from a technical and a political dimension. But social willingness is needed if those technologies are to be adopted. One key dimension for adoption relates to the changes it will incur for teaching and teachers. This section will highlight some key features of smart technologies that may change teaching and the teaching profession.

Teachers as Experts Augmented by Smart Technologies

A commonly asked question is, Will smart technologies make teachers redundant? Whether they are already available or under development, smart education technologies for teaching and learning do not aim to replace teachers or human beings. Not yet, at least. Smart technologies were developed with the current education model in mind. Most teaching and learning solutions are designed as hybrid human-AI systems and require teacher-student interactions and human oversight of the machine at different points. Molenaar offers a model to better understand the continuum between fully automated and teacher-only education. Most advanced personalization solutions either require that teachers intervene or alert teachers when they should intervene, for example, because a student is still struggling or because a student needs to move on to another step of the learning process.[25] Most solutions to support classroom orchestration are also hybrid solutions that merely scaffold teachers in implementing rich learning scenarios for their students. As Dillenbourg puts it, “There is a teacher in the loop” and classroom analytics are designed to support teachers in orchestrating the teaching and learning of students in the class and in providing them effectively with rich learning scenarios—not to replace them.[26]

Contrary to how robots are often presented in other sectors, social robots are not meant to replace teachers but to support students or teachers for specific learning tasks, in the spirit of personalization tools.[27] This is not to say that social robots will never replace teachers. But as of 2022, social robots are effective mainly in accomplishing narrowly defined tasks. They play the role of a teacher's assistant, as computers do in their different way. As for telepresence robots, they merely enable human teachers (or students) to be present from a distance. Good provides an excellent case showing how smart technologies for students with special needs may create new social relationships between learners and the humans in charge of providing them with appropriate learning tasks—rather than suppress them.[28] She shows how a learning environment designed to support the learning of autistic students has created new social interactions and social learning opportunities between the children and the person who operates the program. Sometimes, smart technologies help human beings to connect.

At the system and organizational level, the use of smart technologies follows the same pattern. Early warning systems help predict dropout, but they require human intervention to try to keep "at risk" students from dropping out.[29] Other types of learning analytics used within educational institutions to support decision making also provide information that needs to be acted on; they do not make final decisions in the place of administrators and teachers.[30]

In some instances, however, smart technologies do make decisions and some are designed for full automation. Game-based standardized assessments, for example, do more than provide a suggestion: like traditional computer-based standardized assessments, they automatically score the test takers and assess their skills. But even in this instance they remain sociotechnical systems, that is, systems in which social and technical features interact and are shaped together. Personalization systems, classroom analytics, and early warning systems all make some decisions to enact their next step or recommend one to human beings. But they typically provide input only to decisions or actions that teachers, learners, or other human beings will make. Teachers may be "augmented" by smart technologies, but they remain the experts making the final decisions and handling the complexity of the learning situation.

Teachers as Co-Designers of Technology Solutions

Sometimes, education technology solutions are designed and proposed because they are possible rather than because they will be useful and provide clear benefits to end users in education. Most education technology products are mere educational derivatives of solutions designed for other sectors. Even when technology applications are useful and beneficial, some teachers, learners, and other users may have no interest in using them. Instances of lack of use and lack of usefulness of education technology have given rise to several negative critiques of education technology,[31] even though the increased use of technology in classroom instruction is one of the biggest changes in classrooms of the 2010s.[32]

Involving teachers in the design and testing of technology may help overcome this problem. One reason some education technology products are not used is that they are poorly designed or because they are based on an insufficient understanding of how teachers can use them in their professional practice in ways that support rather than distract them. For example, classroom analytics are useful when they make visible to teachers what is invisible or not easy to see (either in real time or after class) and when they provide information that teachers can act on and interpret.[33]

One aspect of smart technologies that determines whether or not they will be useful to their users is how they display the final information. The interface between technology and humans is essential. For example, research shows that some types of dashboards can be more effective than others in supporting teachers and learners or more appropriate in certain contexts than in others.[34] Dashboards typically display the final output of the analytics: they can take different forms (e.g., centralized, distributed, ambient) and use different display devices. Sometimes they can add to the cognitive load of teachers and confuse rather than help them.

Involving teachers, students, and other end users as co-designers in the research and development of smart technologies ensures the usefulness and use of smart digital solutions. It also helps the people involved in understanding and shaping the social context in which smart education technologies would best be used (the classroom, home, etc.). This involvement of end users should be an aim even when it is challenging, for example, when the end users are students with special needs. While not all teachers would have to be part of research on using digital technology, this involvement could become one of their new roles in the future. At least occasionally, they should take part in the design and piloting of new technologies.

Teachers as Professional Learners Using Technology

The ability to use digital resources as part of one's professional practice is becoming and will increasingly become imperative for all. For teachers and professors, digital skills are less about mastering the technology than about integrating technology tools, resources, and outputs in their pedagogy. Unless fully automated, technology solutions are mere tools for human teaching, learning, or managing education systems. Professional learning opportunities for staff, through training and organized continuous professional learning opportunities, are thus a final aspect that should be an integral part of a strong digital infrastructure.

Digitalization may be part of the solution. Some digital solutions based on games and simulations can, for example, help prepare teachers to deal with class management and certain students.[35] In some instances, though, the usefulness of education technology may go beyond offering a technical solution to a specific problem. Changing the stakeholders' mindset or catalyzing some broader change within an institution or an education system may sometimes be the purpose of technology or data use. In general, innovation is a driver of professional learning and change.[36] Smart technologies play the same role.

Ifenthaler shows that many universities and institutions introduce learning analytics institutionwide in order to change their organizational culture or processes and perhaps sometimes to foster new collaborations and ways of working between different stakeholders within an institution.[37] Providing a solution to a specific problem or automating their processes may be only a secondary objective.

Regardless of the effectiveness of early warning systems in reducing student dropout, one of the benefits of these systems (and the related research) that has already delivered is a better and broader understanding of the circumstances leading students to drop out. Bowers shows that the traditional conception of students at risk of dropping out (that is, students with low and declining grades who do not like school) corresponds to only 38 percent of actual dropouts in the United States—so that traditional interventions miss out on the majority of students who actually drop out.[38]

Beyond providing real-time information, several of the functionalities of classroom analytics provide feedback to teachers on what happened in their class, and one of their virtues can be to trigger professional reflection and learning that is followed by behavioral change and improved teaching proficiency.[39]

Thus, smart technologies provide teachers and stakeholders with feedback and information that help them to reflect on their practices, that challenge some of their assumptions, and that support their professional learning and ultimately improve their teaching practices.

Overcoming the Risks of Smart Technologies: Transparency, Fairness, and Ethics

All these new aspects of teaching can materialize only if some of the risks of smart technologies remain under control. One key element of any sociotechnical system is the broader social context in which the system operates, including its values and principles. Because these systems rely on large amounts of education data, including, sometimes, personal data such as biological markers, face recognition, or expression or because they require permanent monitoring and tracking of learners, classrooms, or institutions, their development and use raises concerns about data protection and privacy as well as ethical and political concerns. Could (or should) education establishments and systems become a new version of "Big Brother" for the sake of improved learning outcomes? Can governments and other parties be trusted to use this information only for educational improvement—and can they be trusted to enforce strong data protection regimes? What could be the adverse consequences of this use, if not done properly, now or in the future, for students and for teachers. Could data-rich education technologies, for example, perpetuate and reinforce biases and inequity? Embracing smart technologies implies some trust in how they are used, trust in their having credible safeguards, and some level of understanding and acceptance of their processes and outputs.[40]

Most OECD countries have strong data protection regulation that ensures that personal education data cannot be shared with (or used by) third parties beyond the educational processes for which they are collected unless certain privacy conditions are met. The Europe Union has the General Data Protection Regulation (GDPR) and the United States has the Family Educational Rights and Privacy Act (FERPA), both of which have inspired the passage of data protection laws in many other countries. Much of the data protection concerns relate to administrative micro-data.[41]

Data protection, however, is just one aspect of data governance. For example, because accurate predictors for early warning systems can rely on minimal information that does not include information about gender, race, and socioeconomic status,[42] the inclusion of these kinds of indicators to diagnose dropout in early warning systems may not be considered ethical (or even necessary) unless they significantly improve the performance of the algorithms. Results that do not include any personal information about learners, however, may still lead to biased or socially/politically undesirable outcomes. Ethical concerns should therefore include a verification and discussion of the effects of smart technologies on different groups and ensure that they are aligned with countries' social and political principles.[43] Because, in practice, few people are able to verify the effects and impacts of algorithms, some independent groups of stakeholders may be responsible for or even assigned this task. While anyone should be allowed to undertake verification in the frame of an open algorithm culture (at least when algorithms lead to a decision or a quasi-decision), education researchers and nongovernmental organizations and, possibly, independent governmental agencies could play an enhanced role in this area.

For the most advanced applications of learning analytics based on a continuous monitoring of individuals (e.g., engagement, self-regulation, classroom orchestration, game-based assessments), another question is whether stakeholders feel comfortable with some aspects of the applications even if they are legal. While the tracking and data collection necessary to power learning analytics focusing on student engagement, self-regulation, or classroom orchestration must comply with domestic data protection regulations (and algorithm regulation, if any), the question is how to make them compatible with the political values of the country where they are implemented. Ensuring compatibility may require some imagination about data protection arrangements (such as deleting immediately the data once processed). As in the exam example mentioned earlier, ensuring compatibility also requires a social negotiation with all stakeholders, including transparency about the data collection and how they are used.

For example, one pragmatic and ethical issue relates to the use of the information generated by data analytics about teachers and other staff. While smart technologies and learning analytics have the potential to provide feedback and support to teachers and other education stakeholders to make better decisions and improve their professional practices, they could also be used against them and thus unintentionally lead to undesirable social behaviors. Classroom analytics can be used to monitor teachers' professional behavior and sometimes identify shortcomings in how they orchestrate learning in their classroom.[44] Should this information be used to sanction or support them?

Because smart technologies can be intrusive, their adoption relies on some level of trust in their positive, human-empowering ethical use. Should their voluntary use have adverse effects on teachers, school principals, and decision makers, they may appear as less acceptable and be resisted. Ensuring that they are used ethically may require full confidentiality in their results or a discussion and clear disclosure of how they can affect the staff using them. (Their effect on the staff using them may also depend on their expected accuracy and effectiveness.) As with the information provided by longitudinal information systems, two different philosophies are possible. Some argue that their information should be used to reward and sanction stakeholders (including teachers) as an accountability mechanism, which is also a way to make them pay attention to the provided information. Others argue that the information should not be used to reward or sanction stakeholders because doing so may lead to their opposing the use of the information or may just motivate them to try to "game the system"—and thus lead to unethical behavior. No consensus has yet been reached about what the best strategy is—but different answers may clearly lead to shaping the future of the teaching profession (and education) in different ways.

Concluding Remarks

Smart technologies that could transform education are already available. Some are more mature than others, but a range of solutions could and will make education systems and establishments operate differently in the future. Some of these tools involve the personalization of learning (intelligent tutoring systems), keeping students motivated and engaged in their learning, and allowing students with special needs to benefit fully from the curriculum. All of these tools support teachers in their efforts to teach their students in a classroom and do not necessarily challenge the traditional teacher-student relationship. Technology can also target teachers directly. Smart technologies based on classroom analytics allow them to orchestrate teaching and learning in their class in real time and post hoc, while social robots can support them as teaching assistants, instructors, and even peer students. Technology has also made big strides in supporting the management of education systems, with a host of solutions at the system and organizational levels to manage budget, study paths, relationships with external stakeholders, and so on that indirectly eases teachers' work. The development of early warning systems to help prevent students from dropping out of high school (or university) is a good example of this progress.

Some of the promises of smart technologies relate to the effectiveness of education. They can support students to achieve better learning outcomes and teachers to teach (and also learn) better. Another promise lies in enhancing equity: technology helps to make education more inclusive and can provide additional learning opportunities to students from more disadvantaged groups—assuming that they are widely accessible and used. Cost efficiency through automation is one aspect that digitalization has brought to many sectors of society and that is also gradually happening in education. At the same time, developing and maintaining technology can be costly, and the public cost has to be balanced against its benefits.

Even if none of these promises of digitalization materializes, digitalization could still open new avenues for formal education and make it more convenient, more enjoyable, or just . . . different and aligned with modern life. Innovation is in itself a source of professional learning for teachers and also for students: it is a means to create new capacity within a system because people have to adjust to the new requirements it promotes.[45] Introducing digital tools in schools and universities may not have a narrow objective but be a tool to trigger change and improvement efforts. It is also a way for formal education to be part of its digital time. Should schools and universities resist or embrace digitalization regardless of what happens in society? While formal education systems should empower everyone to enjoy, access, and learn from all the knowledge and experiences that have been developed by humanity, education should be more than a museum.

Several scenarios are possible.

One scenario would be for education to change minimally and continue to have little adoption of technology and digital resources in teaching and learning. This scenario may mean that most smart technologies would be available privately for out-of-school learning for those who can afford it. The education technology market would continue mainly to target its supply to the informal education market and corporate training. The work of teachers would remain very close to their current role: they would use digital devices from time to time for specific learning tasks.

A second scenario would be for education to look similar, on the surface, but become very different, just as cars and planes look more or less the same way they did forty years ago but have become very different now that they are fully equipped with sensors and computing devices. Education establishments may also become smart buildings with cameras, sensors, and digital devices supporting students, teachers, and administrators in their efforts to make decisions to improve their teaching, learning, and management practices. Technology may also become more prevalent for learning at home, for example, with more intelligent tutoring systems available for everyone to use. The work of teachers would then be informed by a lot of actionable data presented to them through dashboards and through diagnosis tools and recommendations. They would still teach as they do today, but they would benefit from a variety of information about each of their students that would allow them to personalize their teaching.

A third scenario could be for education to build on smart technologies and other social trends related to digitalization to reshape as a social institution. People, including teachers, may increasingly telework, more schoolwork may be done at home, sometimes with more involvement of parents and communities, and social time in school may be used mainly for individual tutoring and collective learning. For example, students can choose to go to school to do some tasks individually or perform them at home while other activities must be done at school with peers and under the guidance of their teachers. Also, after a clear analysis of what could be done remotely and what should be done in person, teachers could telework part of the week. This working pattern may induce more collaboration between teachers and a new division of labor among them.

The last two scenarios would have implications for teachers and the main aspects of teaching but also for what it means to be a student and how parents can support their children. Similar scenarios could be envisaged for the management of education systems and organizations. For example, many administrative processes, from assessments to the allocation of students to different educational institutions, could be fully automated.

Though the future may hold different scenarios or any combination of these three, the ongoing digital transformation and the recent experience of the pandemic make this a good time to think about what is possible and how digital technology can best support the improvement of education.

Notes

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