# Zanzibar Declaration: Sustainable Education in a Digital Age of rapidly Emerging Technologies

Johannes Magenheim, Raymond Morel, Javier Osorio, Don Passey, Christophe Reffay

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# 'Sustainable Education in a Digital Age of rapidly Emerging Technologies'

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**Purpose of the Zanzibar Declaration**
The International Federation for Information Processing (IFIP) was founded in 1960 under the auspices of UNESCO, as a federation for societies working in information processing. IFIP's aim is two-fold: to support information processing in the countries of its members and to encourage technology transfer to developing nations. As its mission statement states: IFIP is the global non-profit federation of societies of ICT professionals that aims at achieving a worldwide professional and socially responsible development and application of information and communication technologies.

IFIP Technical Committee (TC3) is one of 13 Technical Committees within IFIP; TC3 focuses on education, the uses and applications of computing in education, across the lifespan, and across educational sectors (whether primary, secondary, tertiary, vocational, further, higher, professional, or adult). In response to IFIP TC3 member concerns with how education can continue to integrate digital technologies for educational purposes, foregrounding work has explored the topic of 'Sustainable Education in a Digital Age of rapidly Emerging Technologies'. Arising from that work, IFIP TC3 presents this Zanzibar Declaration – a document that is designed to consider and to challenge any or all stakeholders at any level in education (whether teachers, lecturers, academics, researchers, professionals, trainers or policy makers).

This document highlights both potential opportunities and challenges that are offered by emerging technologies for education (and wider society). Major changes in digital technologies arise about every five years, so the contents of this Declaration should be considered in a context of continuous digital technological change. Whilst educators need to be aware of the potential value of uses of emerging technologies in teaching and learning, it is also necessary to be conversant with the concerns and challenges that they bring. The background work that has led to and is presented in this document indicates that full awareness of this balance is vital when considering any implementation of emerging technologies for educational purposes.

**Content of the Zanzibar Declaration**
The document contains four main sections (with the second section divided into 6 further sub-sections):

1. **Background** – an outline of the rationale and process of development of this document.
2. **Introduction** – a discussion of some key challenges and potential opportunities that emerging technologies bring to education, relating to:
   - 2.1 Sustainable education and digital technologies
   - 2.2 Emerging digital technologies and educational potential
   - 2.3 Computing and informatics – 'opening the black box'
   - 2.4 Educational games and robotics to foster engagement and learning
   - 2.5 Virtual and augmented reality to foster motivation and empowerment
   - 2.6 3D-printing to foster customisation and personalisation
   - 2.7 Accessibility and inclusion
3. **The current and the future** – expert views of where we are considered to be at this current time, and how this area might develop over the coming years, related to specific emerging technologies that are of contemporary focal interest
4. **Challenges and opportunities** – expert views of the key challenges and opportunities that are considered likely at this time, related to each of the specific emerging technologies

## 1. Background

In 2015, the United Nations agreed its 17 Sustainable Development Goals (SDGs), and these included a key goal for education (SDG4): "Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all".[1] The International Federation for Information Processing (IFIP) Technical Committee 3 on Education (TC3) is fundamentally concerned with how this SDG can be implemented and sustained when digital technologies are used to support education and its contexts worldwide. The Covid-19 pandemic highlighted some of the ways that digital technologies can be deployed to ensure education provision during periods of crisis and lockdown. As a consequence, the potential for digital technologies to support education has been widely recognised. A report from the World Bank, UNESCO and UNICEF (2021)[2] states this clearly, saying that: "Countries have an opportunity to accelerate learning recovery and make schools more efficient, equitable, and resilient by building on investments made and lessons learned during the crisis. Now is the time to shift from crisis to recovery – and beyond recovery, to resilient and transformative education systems that truly deliver learning and well-being for all children and youth."

A Transforming Education Summit convened by the United Nations Secretary-General was run in September 2022[3]. The rationale for the September Summit was stated as: "The Summit is being convened in response to a global crisis in education – one of equity and inclusion, quality and relevance. Often slow and unseen, this crisis is having a devastating impact on the futures of children and youth worldwide with progress towards the education-related Sustainable Development Goals badly off track." Thematic Action Tracks convened at the global level place a spotlight on the areas that require greater attention and action: "Inclusive, equitable, safe and healthy schools"; "Teachers, teaching and the teaching profession"; "Learning and skills for life, work and sustainable development"; and "Digital learning and transformation."

In this context, concerns about sustainability of quality and inclusive education through uses of digital technologies are influenced by the ongoing changes in the digital technologies themselves. It is this focus, a concern about sustainability that adequately accommodates emerging technologies, that IFIP TC3 reports through this Declaration document.

IFIP TC3 agreed in its Annual General Meeting in April 2019, held in Zanzibar, Tanzania, to initiate development of a declaration on 'Sustainable Education in a Digital Age of rapidly Emerging Technologies'. The intention for the 'Zanzibar Declaration' (ZD) is that it would focus on future educational challenges that arise from rapidly emerging technologies impacting societies and communities. In this respect, it would be closely related to the UN's Sustainable Development Goal 4 (SDG 4: Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all).

Experts from different disciplines and from across a number of TCs of the IFIP were invited to a subsequent series of four webinars in 2021. Together with practitioners, decision-makers, and researchers from the education sector, they discussed specific questions regarding their awareness of contexts concerned with each topic. As a basis for finding topics for these webinars, a matrix was used. The matrix consisted of various emerging information technologies (IT) positioned against different social areas in which these technologies were applied, with corresponding social effects listed. For the four webinars,

[1] United Nations Department of Economic and Social Affairs (n.d.). https://sdgs.un.org/goals

[2] The World Bank, UNESCO and UNICEF (2021). The State of the Global Education Crisis: A Path to Recovery. Washington D.C., Paris, New York: The World Bank, UNESCO, and UNICEF. https://www.worldbank.org/en/topic/education/publication/the-state-of-the-global-education-crisis-a-path-to-recovery

[3] United Nations (n.d.). Transforming Education Summit. https://www.un.org/en/transforming-education-summit

four thematic clusters of digital technologies and social impact areas were identified that were not entirely free of overlap, but were of specific interest for education. A further panel session discussing other topics was held during the IFIP TC3 WCCE 2022 conference. Details of the ZD process, the four webinars (videos and outcomes), the panel session held during the IFIP TC3 WCCE 2022 conference, and the ZD grid, can be found on the ZD website: https://zanzibardeclaration.cicei.org.

The educational and social implications arising from emerging digital technologies that are considered in this Zanzibar Declaration are:

- Computer Networks and Communication on the Economic and Ecological Transformations of Society;
- Computer Networks and Communication and Mobility;
- Cloud Computing, Privacy and Social Surveillance;
- Social Impacts of Big Data Analysis and Machine Learning;
- Power of AI-Methods and Algorithms for Decision-Making;
- Recognition (Tracking), Enduring Information and Quality of Information;
- Virtual and Augmented Reality;
- 3D/4D Printing and Energy;
- Humanoids and Digital Equity;
- Robotics and Decent Work; and
- Ethical Issues of Autonomous Systems.

## 2. Introduction

### *2.1 Sustainable education and digital technologies*

It is recognised that social adoption of technological innovation for sustainability is important, if wide practice to support educational needs are to be met. However, there are important considerations if such social adoption is to occur. For example, bandwidth and latency are important; availability in fixed and mobile locations, network neutrality, distribution of accessibility and quality are parameters that determine the extent and qualities of present and future networks and are also decisive for enabling different forms and potentials of educational applications. In this context, it is recognised that the market for mobile subscriptions is growing faster than for fixed subscriptions. In parallel, 5G technology is likely to provide sufficient technical characteristics for a very wide range of applications. However, mobile network distribution is not equal all over the world, and mobile devices may not be ideal for all educational purposes.

The increasing availability of mobile devices and the networking of learning spaces via internet technology is, nevertheless, changing the traditional concept of the 'classroom' from a local to a virtual space. This change has been accelerated by recent global events, such as the waves of pandemics and political conflicts. Subsequent development is characterised by keywords that have been associated with this shift - pervasive and ubiquitous computing. Given the internal computing systems employed, the type of data collection in learning processes and its evaluation can be expanded accordingly. This could involve the forms of emerging technologies discussed in this document, and would use what have been and are termed artificial intelligence (AI) methods, taking student-centred data derived from uses of mobile devices, wearable computers, global positioning systems (GPS), radio frequency identification (RFID) tags, sensors, pads, and badges, as well as wireless sensor networks. The diverse data sources accessed through mobile learning can also provide the basis for sentiment analysis. It is argued and shown in specific cases that AI methods combined with pervasive technology can allow for a better knowledge of each student's requirements and problems, and can identify paths to personal achievement (a student's level of knowledge, speed of learning and desired goals, and a student's feelings about learning). However, accessibility to these systems, and understanding how to benefit from them, are not widely in place.

In terms of classroom education, it has been shown that the one-to-many learning situation in a classroom can be significantly expanded through the virtual classroom without the individualisation of learning having to suffer (with a combination of face-to-face learning, synchronous and asynchronous e-learning). However, the development of suitable learning materials and an adequate learning design is an essential prerequisite. In this context, inter-school networks can connect schools and provide crucial infrastructure and services (e.g. archiving, backup, storage, school applications, local storage, and whole-class teaching tools) to support the enhanced use of digital technologies in schools by connecting public and private clouds and communities. Additionally, school networks can enable highly collaborative open learning, student-centred learning, problem-based learning, critical pedagogy, and creative activities. At a wider level, regionally managed networks are not necessarily restrictive; they can offer choice for customisation of learning environments, considering specific curriculum aspects and needs. They can support the management of information and facilitate the synergy of engagement with parents and those in other schools. Similarly, networks can support community building, shared education, and joint learning opportunities. However, the introduction of networks in schools does not necessarily close the digital gap. Despite high investment in infrastructures, Wifi access, and free device loans, some agents (e.g., parents, educators, institutions) may not actively foster children's engagement in using digital technologies in education. In this respect, education (with or without uses of digital technologies) only works when there is an open learning attitude on the part of all stakeholders. There is an associated need in particular, as such network-based learning environments require continuous professional development for teachers.

In the current context, uses of digital technologies to support synchronous, asynchronous, blended and hybrid learning provision have been applied and discussed widely. Different forms of open and distance learning can certainly be characterised by the parameters of high versus low bandwidth, high versus low immediacy, and synchronous versus asynchronous learning opportunities. Even with growing access to the Internet and wireless communication, inequality in broadband access and educational gaps in operating a digital culture tends to reproduce and amplify class, ethnicity, age, and gender structures of social difference between countries and within countries. Network-based open education is characterised by open admissions, open curricula, open educational resources, online learning, transnational education, and learner-initiated pedagogy. However, open education does not necessarily mean it is free of cost. Open online learning offerings require a balance of cost, access and quality factors. At an international level, computer networks enable learning and working with people in different parts of the world and thereby can create new social networks. Thus, computer networks can foster sustainable development goals by initiating projects with real social impact and applying problem-based learning to real-world problems. However, successful network-based projects require close collaboration between stakeholders to ensure a project creates value for partner organisations and communities. Given this form of potential, it can be argued that environmental, social and economic sustainability should be based on a holistic view of society.

### *2.2 Emerging digital technologies and educational potential*

Potential educational benefits of emerging technologies are not necessarily widely recognised. One of the reasons for this lack of wide understanding is that, for example, automated learning analytics and its applications need to be critically examined before benefits can be clearly understood or advocated. In this same context, the usefulness of machine learning and big data assessment depends on the application context. Whilst education needs to be holistic in its aims and to build on diverse interdisciplinary perspectives, importantly, education is not only concerned with content knowledge, but also with agency (to enable students and teachers to work, innovate, and anticipate the impact of technology). Hence, we must avoid 'Learnification', where learning is always broken into small pieces.

The meanings of many new and emerging concepts in the field of digital technologies are not necessarily widely known or understood in education. For example, the terms 'Data Science', 'Data Analysis' and 'Data Mining' are not necessarily understood widely by teachers in classrooms. Indeed, behind the terms are different meanings and concepts, and these must be clarified to avoid misinterpretation in communication between stakeholders from various professional areas if ways to consider emerging digital technologies are to be taken forward in a way that everyone can understand. It is fundamentally necessary to understand what data gathered by and presented by digital technologies are saying; interpretation of data within context is essential and this is likely to require teams with a variety of competencies to work on them to make them usable and accessible to specific audiences.

Similarly, there is no uniform definition of autonomous systems, which are both of interest and concern to educators. Autonomous systems differ in the real world primarily in terms of their degree of autonomy and freedom to make decisions independently of humans. The software and algorithms of 'autonomous systems' often use machine learning techniques and use deep neural networks, which require vast amounts of data. Therefore, their implementation is associated with severe ethical issues (e.g. if the gathered data are of sufficient quality and do not generate biases). If a system fails to evaluate big data correctly, we tend to blame the data, perhaps ignoring our responsibility to gain those data and identify the reliability of their sources. It is necessary to address, rather than avoid, these professional responsibilities. In moving forward, extraordinary care should be taken to identify and mitigate potential risks in machine learning systems. A system for which future risks cannot be reliably predicted requires frequent assessment of risk as the system evolves in use; otherwise, it should not be deployed.

Ethics should be at the forefront of the development and the deployment of autonomous systems. Ethical considerations are clearly important when using internet platforms. In particular: considering disinformation and propaganda causing distrust in established social institutions such as media, medicine, democracy, and science; addiction and the dopamine economy especially related to social media platforms and games, data control and monetisation (in so-called free apps); implicit trust and insufficient user understanding; hateful and criminal actors; and the surveillance state. Even in the development phase of autonomous systems, respecting human rights, protecting individuals' privacies, and empowering people to complete tasks should be essential guidelines ("Every line of code has a moral and ethical implication" according to Grady Booch (2015)[4]). It should be recognised that AI is not independent of humans, but is integrated into a socio-technical context of action between humans and machines. This can result in various issues: human interaction confusion, obligations, accountability, transparency and explainability of the system ethics. Autonomous systems are mostly not fully autonomous and independent from the human user and are usually embedded in a socio-technical action. On occasions, the time for decisions by the human actor in time-critical action situations is often limited and essentially determined by the decision alternatives of the AI system specified in its algorithms. Nevertheless, programmed decisions should reflect ethical, cultural and legal values. Therefore, from an ethical perspective, autonomous systems can challenge established assumptions about responsibility and the judgement of guilt. The responsibility for the design of algorithms of autonomous systems and the selection of their data for the generation of decisions or proposals for alternative actions should not be left to a single developer but should be the responsibility of a (multidisciplinary) team. In this context, the relationship between man and machine is not a new problem from a historical perspective.

The development of 'new software' has always included the question of responsibility and underlying ethical issues. The primary concern for autonomous systems in education is the proactive application of ethical standards to all aspects of the work of computing professionals, using commonly agreed-upon standards. Computer scientists need to emphasise professional responsibility (standards of safety and software development, making software engineering tools, articulating professional responsibility for their work). Therefore, computing professionals should articulate their responsibility and ethical standards and formalise them in codes of ethics. The IFIP Code of Ethics and Professional Conduct (2022)[5] and the current draft of the ACM Code of Ethics (2018)[6] provide a global conciseness of this concern for the profession. However, viewing autonomous systems through the lens of ethics provides too narrow a focus; the real issue is the impact on society.

As previously stated, automated decision-making systems are never fully automatic, but are based on an interaction between software and human actors. When the AI methods are applied, the quality of the data used and the process of interactive model adaptation are

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[4] Grady Booch (2015). The Future of Software Engineering. Keynote Speech at ICSE 2015, https://www.youtube.com/watch?v=h1TGJJ-F-fE&ab_channel=ICSEFlorence

[5] IFIP (n.d.). IFIP Code of Ethics. https://ifip.org/index.php?option=com_content&task=view&id=267&Itemid=679#:~:text=IFIP%20Code%20of%20Ethics%20The%20purposes%20and%20values,of%20IFIP%27s%20member%20societies%20and%20the%20wider%20profession.

[6] ACM Ethics (n.d.). Code 2018. https://ethics.acm.org/code-of-ethics/code-2018/

essential criteria for the quality of the results achieved (such as classification, or prediction). To achieve good results as a human actor in the decision-making process (e.g. pattern recognition in microbiology based on images, prediction of developments such as the course of a pandemic), sound knowledge of the mathematical and informatics concepts underlying machine decision-making systems is required. Automatic decision-making systems (ADMS) apply different AI concepts, partly in combination: machine learning and deep learning, supervised learning (e.g. regression, vector machine, decision trees, random forest, neuronal network) and unsupervised learning (e.g. K-means, cluster analysis (hierarchical), Density-Based Spatial Clustering of Applications with Noise (DBSCAN), auto-encoders).

To improve the quality of the data underlying the applied AI methods, various parameters of data extraction, preparation, and data cleansing (noise removal) must be considered: user-centric or model-centric views of the data, sources of data (human or sensor, structured, semi-structured, unstructured), incomplete (missing values) and uncertain data, small sample size, data augmentation without bias, etc. In the process of interactive decision-making between ADMS and humans, the expertise of the human factor plays an essential role in the quality of the predictions. The complexity of the predictive model used (number of parameters), the quality of the data used (estimation of bias effects), and the quality of data visualisation must be designed and balanced in such a way that the interpretation of the results, provided by the ADMS, delivers reliable predictions based on reasonable model assumptions.

In the OECD, projects are investigating the connection between smart data, digital technologies and education. There are different focal points in this context: AI applications in terms of personalisation of learning, in terms of classroom analytics, and in terms of support at an institutional level for educational management purposes. The use of intelligent tutorial systems has been talked about for many years. Through the further development of AI methods and the expanded possibilities of recording learner data, there are also many possibilities for individualising and personalising learning (e.g., tracking a student’s activities in a computer-based learning environment, or face recognition (sentiment analysis)). Mood trackers and eye-gaze devices, for example, have been used to support students with specific learning disabilities, while response systems have been used to differentiate learning tasks for individual students within a class (to analyse where the students are on a specific learning curve and what their following exercises should be). The second group of applications of AI methods in learning analytics relates to classroom activities. Whilst there are clear ethical concerns and issues that need to be addressed, nevertheless, there are examples of video recordings and their evaluation used to record teacher-student and student-student interactions in the classroom and to evaluate them both on a formal communicative level and in terms of their content. It is reported that the (partially) automated evaluation of such data can provide the teacher with important information about the lesson’s quality and its future learning design. This type of data collection raises critical privacy issues concerning data protection for the students and the misuse of the data, e.g. assessing teachers’ behaviours. A third group of learning analytics applications at the level of educational management can attempt to map educational processes at the institutional level and, in this way, serve, for example, as an early warning system to reduce the dropout rates in a study programme. For this purpose, for example, students’ test results and acquired certificates are examined. However, other data such as gender and the social background of the students are often collected as well. Here, too, privacy issues arise, and the principle of data minimisation needs to be observed. In this way, AI can be used as a class monitor to support learners and teachers. In this case, AI software provides teachers with essential clues about what is happening in the classroom by collecting and evaluating a wide range of data gathered from pedagogical interactions in the classroom. In the process, cameras and other input and recording media capture and assess the following data: classroom interaction, scanning faces, face recognition, and classification and storing of data (students’ behaviour, and facial emotions by applying deep learning methods with neuronal networks). Reporting and analysing the data by human action detection algorithms suggests to teachers necessary interventions for the classroom and daily notification to parents via an App. The AI class monitor enables students to utilise individually adapted learning opportunities for adaptive self-regulated learning (adaptive quizzes). The varying acceptance of such systems in education in different countries highlights the importance of the cultural, social and legal contexts when evaluating AI and autonomous systems from an ethical perspective. The importance of the cultural and social context in which data are collected and analysed with AI methods also becomes evident in the case of image processing. Additionally, ethical biases can be produced during data training. To enable students to understand the fundamental functioning of such autonomous systems and their impact on society, informatics education is necessary for all. Hence, informatics as a science should be a compulsory part of education and should be treated as important as mathematics, the sciences and languages. Informatics as a tool should also be integrated into the teaching of all disciplines.

Another application of ADMS that is increasingly concerns plagiarism detection and the smart classroom, which provides teachers with various student and classroom-related interaction data. However, the question remains whether it is realistic for smart classroom concepts to become widespread in educational practice or whether the scepticism of the people involved (parents, teachers, students, decision-makers) will prevent their spread. The application of AI for the needs of educational management is still in an emergent stage. During the transformation phase of traditional data collection (such as interviews, or tests) to AI-supported evaluation systems employing semi-automated collection systems in the educational sector (smart classrooms), the question arises as to what extent the data collected based on small data collections in a specific learning situation (e.g. a classroom) can be generalised without further consideration. In interpreting the data, the context of any survey and the question of generalisability are critical problems to consider.

### *2.3 Computing and informatics – ‘opening the black box’*
IT systems rely upon foundations that are based in computing and informatics. Greater awareness and use of computing and informatics allows not only an understanding of the basis of opportunities and challenges, but provides the potential to act in order to address issues and to develop activities and use. The longer-term development of this greater awareness and use of computing and informatics is being enacted in many countries through increasing implementation of computer science education in schools.

### *2.4 Educational games and robotics to foster engagement and learning*
Gamification and game-based learning are relevant application examples of AI concepts in education. Game-based mechanics, aesthetics and game thinking are expected to engage people, motivate action, promote learning and solve problems by issuing rewards to foster desired actions and outcomes. However, game design should keep different ethical considerations in mind: bias in gamification design (game rules are created by teachers/game designers, not learners); privacy (game results and play statistics could be visible to others); and voluntary participation (no one game participant should feel left out). In game-based learning, the voluntary participation of learners needs a ‘safe to fail’ environment. Learners need the freedom to fail, recover and learn from the failure and thus should then be encouraged to take on challenges they would not have undertaken otherwise.

Gamification and ambient environments supported by AI can be a useful approach to introduce AI in the classroom, even for younger pupils. Teaching AI-concepts should be intuitively managed, especially for young ages. AI can also contribute to sustainable education by personalising learning environments and increase availability and accessibility to learning resources and knowledge. However, organisational change is necessary if teachers are to use AI-systems, so that these uses can lead to effective teaching. There is a need to heed a warning about inscrutable AI-systems; there is a critical need for explainability (for recipients) and social accountability (for machine learning-designers) of AI-systems.

Robotic systems in education also use AI technologies. The functions of a robot in the industry are significantly different from those that are used in education. Whereas in industry robots are assigned roles such as increasing productivity, improving customer experience and delivering automation at a significant scale, in education they can fulfil completely different requirements: tools that assist a teacher, learning companions for students, or an autonomous teacher who provides some unit of instruction more or less entirely. As classroom assistants, they can ask questions, providing information, commenting on answers, responding to requests, and recognising individual students and maintaining a record of those interactions. Besides the advantages of using robots in schools (helping students to learn and to understand how they work by programming them), there are also several concerns. These include technological limitations in AI's ability to recognise speech; if robots replace teachers and students just interact with robots, then will they be harmed if their social interaction is minimalised; there is so much a teacher, but not a robot, can do (as AI is not the same as human intelligence).

### *2.5 Virtual and augmented reality to foster motivation and empowerment*

The use of digital technologies during lessons, especially using virtual and augmented reality learning environments, has been shown in specific cases to enable student-motivating learning from early ages upwards and can empower them to use mixed reality to create their own experiences and foster a better understanding of their subject area. Virtual and augmented reality learning environments refocus from consumption to creation. They blend two environments (virtual and real), but the learning should be located in a physical learning environment and in a specific context. The application of these learning environments in the classroom means that there is new knowledge that goes beyond existing technology, pedagogy and content knowledge, and teachers need that specific digital technology knowledge to support students to build their programming and digital artefacts.

### *2.6 3D-printing to foster customisation and personalisation*

3D-technologies are becoming more and more pervasive in our everyday life, and with more accessible prices. Customised products can be produced applying this rapid manufacturing technology. Thus, 3D printing presents a new way to potentiate services and interventions, not only in health areas (surgery planning, building different kinds of prosthetics and orthotics), but also in education and training, e.g., of health professionals. 3D-technologies can also be applied to reverse engineering, where products are deconstructed to extract the design information from them. Using this process, it is possible to determine how a part was designed in order to recreate it. This process is particularly useful for reproducing with 3D printing any parts and products that are needed, but which are no longer available on the market. In education, 3D printing can be used by teachers to construct customised learning materials. As a learning subject in the classroom, students can use 3D printing (especially in vocational education) to learn about CAD/CAM production methods and their possible impact on future jobs.

### *2.7 Accessibility and inclusion*

In the context of any digital system, accessibility and readability are essential categories that ensure the quality of information. Individuals should be enabled to recognise the quality of the information provided by a computer system, e.g., on a website. They should be able to make their own views and judgments when they can gather details accessible via computer systems. Legal aspects can provide a basis for readability and quality of information. The European Accessibility Act and the Web Content Accessibility Guidelines (WCAG) can be considered as legal bases to ensure the readability and quality of information. The WCAG contain four principles (perceptibility, usability, comprehensibility, and robustness), 13 guidelines, and 78 success criteria as key characteristics to make information accessible. Information quality also concerns equal and barrier-free access to information and should disclose tracking techniques used on a website for the user (e.g., user-controlled management of cookies, access to hidden alternative text on a website). Quality of information should consider the trustworthiness and credibility of the source of information and its correspondence with reality. The ability of individuals to critically evaluate the information provided is an essential aspect of information literacy. Therefore, important criteria of formal and content-related information quality should be a subject of teacher training. Similar design principles apply to the design of virtual learning environments using VR and AR techniques as they apply to the design of websites. In particular, the WCAG should be observed. Since mixed teams of experts from different fields often work together to design such learning environments, compliance with such rules is particularly important. For example, the orientation of individuals in such environments should be facilitated by providing an adequate colour contrast ratio and a well-structured navigation system. This should consider especially the needs of individuals with visual impairment, as they should be given barrier-free access to such learning environments. Digital technologies have been developed and used to support those who are visually disabled and with hearing disability, for example, as well as vulnerable people who may be elderly, for example.

## 3. The current and the future

In this section, experts give their views about where we are at this current time, and how this area might develop over the coming years. These views are related to specific emerging technologies that are of contemporary focal interest.

| Emerging technology | Where we are at this current time | How this area might develop over the coming years |
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| Computer Networks and Communication on the Economic and Ecological Transformations of Society | Information technology infrastructures include power supplies, cable connections, satellites, mobile networks, and internet servers. Failures of cable or satellite connections and power cuts cause disruption of services, which make schools that depend on them vulnerable. (Dr Jaana Holvikivi)<br><br>We have merely scratched the surface in defining the impact of the information and communication sciences on the social and ecological transformations of society, particularly in understanding the economies of networking and spatial-temporal transcendence for the global educational and knowledge generating enterprise. (Dr Alexander Flor)<br><br>The power of well-planned and managed networks holds the key to unlocking pupil potential for curiosity and collaboration in the future. I believe that the world has developed their networks rapidly to meet a pandemic problem. Post-pandemic, we need to reflect and perhaps prune back on technology that is not fit for purpose in order to flourish. (Corinne Latham)<br><br>On the one hand, connectivity is increasing and more people than ever have access to the Internet - and all the positive elements that brings, in terms of access to information and education. But on the other hand, we also see more countries enforcing censorships and limiting the free access to information (for example, in Russia with the current war). Along these lines, we also see organised and very efficient spreading of fake news, which might be especially efficient towards some of the less-educated and more vulnerable groups of people. Also, Covid-19 has unfortunately strengthened the digital divide, making it hard for people without Internet access to stay in touch. In 2021, it was still less than one third of the population in the least technologically-developed countries which had Internet access (https://www.statista.com). (Prof Jens Pedersen) | Digitalisation is dependent on physical infrastructures, software platforms and applications. In the current situation, the largest challenges to the digitalisation of education are in the extensive use of internet platforms and cloud-based services such as Zoom, MS Cloud, Facebook, Tiktok, Youtube, Google services, Whatsapp, etc. This has led to a dependence on global technology giants. Particularly the situation after the COVID-19 pandemic school closures has revealed immense global inequalities and disparities in online education. (Dr Jaana Holvikivi)<br><br>The next few years will see the global academic community revisit the first principles of the information and communication sciences to arrive at a greater appreciation of their fundamental role in charting our educational futures. (Dr Alexander Flor)<br><br>Educational technology is intuitive and responds to the needs of learners. As learners continue to grow in their confidence of digital technology, our eco-systems will change in relation to the conditions we find our schools in. (Corinne Latham)<br><br>I hope that affordable and uncensored access to the Internet will continue growing, but I am not so sure about it. (Prof Jens Pedersen) |

| Emerging technology | Where we are at this current time | How this area might develop over the coming years |
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| Computer Networks and Communication and Mobility | Modern society, for good or bad, is now tightly coupled to fast and efficient communication. Imagine just over a century ago just prior to the invention of broadcast radio; communication was slow, ideas, news and political discourse was limited to word-of-mouth, newspapers and physical mail via the postal system. Today, with modern computer networks and the global-spanning network of networks called the Internet, we potentially have gigabyte per second speeds at the domestic level that allow the transfer of information such as ultra-high definition streaming video content, videoconferencing, telepresence, resource sharing, and instantly connecting people world-wide, irrespective of where they are, on a scale never seen before. The extremely rapid development of vaccines for Covid-19, for example, would not have been possible if scientists were not able to share their research data and ideas though communication channels provided by fast and efficient computer networking infrastructure and protocols. (Dr David Herbert)<br><br>The COVID-19 pandemic accelerated the digital transformation of higher education (enforced digitalisation) while mobile technology-mediated learning was implemented by many university students as it supported online learning. Digital natives intend to continue to use their mobile devices for educational purposes; the mobility and autonomy of self-directed learning can enhance students' interest and engagement with their studies. (Dr Kleopatra Nikolopoulou) | Faster networks are on the near horizon. Terabyte per second speeds have been tested in real-world settings, and inevitably, local networks such as those found in the home will see dramatic speed and capacity increases. This will also assist the already-seen huge increases in home automation technologies, which are one facet of the Internet of Things (IoT) - smart devices connected to the network that sense and possibly control aspects of the home environment. With an increase in speed, this also facilitates remote processing possibilities – servers based in the cloud sending and receiving data in real-time as if the processing was performed locally. The game industry is already leveraging this paradigm, with game content that consists of advanced high-resolution graphics delivered to local clients that don't need to possess significant processing or storage requirements. (Dr David Herbert)<br><br>After the COVID-19 pandemic, mobile learning is expected to play an increasingly important role in university teaching and in hybrid-blended courses. The debate regarding the potential of mobile learning to strengthen the digital transformation of university in the post-pandemic era needs more attention; mobile technology-mediated learning is a pragmatic and sustainable approach. Since digital transformation involves adjustment, educational policies could be re-considered to adopt hybrid-blended modes of education (these can be supported by mobile practices) and enhance organisational, technological, and academic management. (Dr Kleopatra Nikolopoulou) |
| Cloud Computing, Privacy and Social Surveillance | The current environment on the Internet has eroded trust in online information. Still, there are systems that people do not even suspect, such as the IoT [Internet of Things] in household appliances, vehicles, and the like that collect data and send these to companies. When people use applications, they seldom understand the full extent of what those apps do, and what kind of data they appropriate. (Dr Jaana Holvikivi) | The complexity of modern systems and the wide extent of hazards in their use will need to be addressed by strong support from technical and educational experts. Technological transitions need support in the form of considerable expertise and involvement of the communities to ensure sustainable solutions in education. (Dr Jaana Holvikivi) |

| Emerging technology | Where we are at this current time | How this area might develop over the coming years |
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| Social Impacts of Big Data Analysis and Machine Learning | The dangers of BDA/ML (Big Data Analysis and Machine Learning) are becoming more and more apparent; however, the larger understanding and political will to direct this in a useful/meaningful manner is still missing. We will need regulation to direct BDA/ML to help in achieving educational aims, and not derail them. (Gurumurthy Kasinathan)<br><br>We are at an interesting junction – where the benefits of detecting learning problems at an early stage are wrestling with ethical/moral/legal issues associated with 'secret' tracking of student behaviours. (Dr Andrew Fluck)<br><br>It is early days yet and we still have to explore more meaningful ways to harness big data to aid educational decisions. (Dr Radhika Misquitta) | Hopefully, with greater research and advocacy from groups like ours, we may be able to alert wider civil society and governments to regulate EdTech. I am not optimistic that we will be able to make major achievements though. (Gurumurthy Kasinathan)<br><br>Different jurisdictions will solve these dilemmas in various ways: hopefully so students can opt-in for enhanced educational services and have control over any identifiable data gathered from them. (Dr Andrew Fluck)<br><br>In the coming years, I hope to see immense growth in this area. It has great potential to support personalised and targeted instruction for all students. (Dr Radhika Misquitta) |
| Power of AI-Methods and Algorithms for Decision-Making | There are still very few decisions made by machines in education, although algorithms make decisions to support different stakeholders: learners when they use intelligent tutoring systems or go to a study/career guidance platform making recommendations; teachers and school principals when they diagnose that some students are at risk of dropping out from school; policy administrators when they allocate or support the matching of students to different public institutions based on a set of pre-defined criteria. Some of the challenges are to make those algorithms more effective, ensure they are equitable and do not amplify inequity, and make them socially acceptable. (Dr Stephan Vincent-Lancrin)<br><br>I feel that we are at an exciting stage where, whilst AI is not new and is well-used in the business sector, it is making its foray into the educational section. (Dr Doreen Ang)<br><br>We are just starting to ride the crest of the wave with AI in K-12 education. As we know, schools are always slow with the uptake of highly specialised technologies, therefore the next decade will be a time for monumental changes in the way we interact with our students. (Dr Therese Keane) | AI in education will continue to advance and develop, as in other domains of society. Some applications such as classroom analytics will become more prevalent. There will be more use of those solutions, but how to make sure they are really useful, effective and equitable will likely remain at the centre of discussions around digital education. (Dr Stephan Vincent-Lancrin)<br><br>As the awareness of AI can be used particularly in higher education, I do believe that there will be more innovative ways in which AI could perhaps be leveraged upon to help enhance learning experience. If this meets with widespread acceptance, there is hope that mainstream schools would eventually explore options. (Dr Doreen Ang)<br><br>Areas of development in K-12 classrooms include using learning analytics to customise student learning needs, the further immersion and development of intelligent tutoring systems and smart classrooms, and finally the introduction of undertaking testing and examinations using AI monitoring techniques to assist the classroom teacher. (Dr Therese Keane) |

| Emerging technology | Where we are at this current time | How this area might develop over the coming years |
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| Recognition (Tracking), Enduring Information and Quality of Information | There is a growing interest in applying concepts related to neuroscience in the field of education. The goal is to reliably measure physical responses of individuals using neuroscience-based recognition systems to improve the teaching-learning process. Recognition devices that, among others, can record and measure facial emotions, body magnitudes or track the eyesight of the observed agents, are becoming more common in laboratories and education-related research. However, a considerable part of the recognition devices are still expensive and have the limitation that they can only be used in laboratories, where the observed individuals are in a closed and controlled environment. (Prof Javier Osorio) | In the coming years, neuroscience-based recognition devices will reach affordable prices and will be primarily wearable, making it possible to obtain a large amount of data from individuals in open environments and without direct control by the observer. (Prof Javier Osorio) |
| Virtual and Augmented Reality | Virtual Reality and Augmented Reality (VR/AR) technology has significantly advanced in recent years, making the field more practical to deploy in diverse areas. Tether-less designs, increased processing capabilities, higher resolutions, increased sensor and camera capabilities as well as weight reduction have meant greater accessibility and versatility of the technology. A long-term and successful application is that of the US air force using VR/AR systems to train their pilots with increasingly realistic systems. (Reported in the Times, August 23rd). (Dr Soonja Yeom) | As advances in the technology are increasing exponentially, it is anticipated there will be major and continual developments in areas where the technology is applied. The game industry has already adopted AR/VR systems, and the gamification field is already proven as another highly successful method to educate people. Modern technologies such as AR and VR can therefore be seen as methods that can be combined to further enhance the possibilities, especially in gamification, of achieving greater successful educative outcomes. (Dr Soonja Yeom) |

| Emerging technology | Where we are at this current time | How this area might develop over the coming years |
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| 3D/4D Printing and Energy | At the moment, I believe that we are in a phase in which 3D printing has become widespread in the domestic market and we are in a new phase on innovation in the study of materials to be used for 3D printing. Not only in the type of material, with the wide range of plastic materials, TPU/TPE, resin, metal etc., but also in the search for developing more ecological, sustainable, biodegradable and biocompatible materials (e.g. cork mixed with aggregating polymers). (Dr Marcelo Brites-Pereira) | I think that, in the domestic market, this will become more and more plug-and-play and will become part of schools and families in their daily lives, allowing them to create new things and give people the opportunity to up-cycle products by repairing them, or allowing them to develop solutions adapted to their needs. This will make each of us a little maker, and it allows us to reduce production costs and wasting materials. On the other hand, I believe that companies… will give the customer the option to buy complete furniture with all the accessories, or buy furniture with access to a database of accessories for the customer to print at home and assemble. In the industrial sector, I believe that the trend is for printers to be increasingly part of the production process and not just part of the prototyping process. There are already automotive companies that produce vehicles with printed components, and this will force the printing process to become faster. In the health area, with research into new materials, I think that we will increasingly have prostheses and even organs made using 3D printing biocompatible materials and genetic materials from the recipient, providing prostheses with a longer lifespan, with better compatibility with the patient, minimizing the risks of material rejection. (Dr Marcelo Brites-Pereira) |
| Humanoids and Digital Equity | Humanoids provide a benefit to those already engaged in the digital world; we need to think about their potential for increasing engagement among the unengaged and the disadvantaged.(Dave Donaghy) | Research and development effort on humanoids to encourage and facilitate initial access to the digital world, especially by cross-specialism collaboration. (Dave Donaghy) |
| Robotics and Decent Work | Robotics is not a new application of digital technologies, but certain features are enabling wider applications and uses. Robotics have been used in industry and in health for many years, but the application of robotics for educational and social purposes is relatively recent. (Prof Don Passey) | Robotics are likely to develop as facilities for language interaction through digital applications develop further. Diversity of robotics is likely to increase, just as the diversity of mobile devices has increased over the past years. (Prof Don Passey) |

| Emerging technology | Where we are at this current time | How this area might develop over the coming years |
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| Ethical Issues of Autonomous Systems | At the current time, there are interesting applications of the use of autonomous systems in industry and business as well as much promise; but generally, the public displays a certain nervousness about their widespread deployment in critical situations. The ethics of autonomous systems will scarcely feature in the schools' computing curricula but may receive some attention in higher education computing. (Prof Andrew McGettrick)<br><br>Ethical issues in online learning, like data privacy, academic integrity, voluntary participation, and technology access, are intensified as e-learning has become increasingly popular in recent years. (Dr Lin Zhang) | Over time, autonomous systems are likely to increase in number, sophistication, and relevance as well as impact on business, industry, and everyday life including education; the related ethical issues will become even more important to the entire community generally and often be more sophisticated, requiring deeper attention and study in education at all levels. (Prof Andrew McGettrick)<br><br>Regulatory bodies, educators, and technology solution providers will each react to those identified ethical concerns and devise solutions, but adoption will likely vary wildly from region to region. (Dr Lin Zhang) |

## 4. Challenges and opportunities

In this section, experts give their views about challenges and opportunities that relate to specific emerging technologies of contemporary focal interest.

| | Challenges | Opportunities |
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| Computer Networks and Communication on the Economic and Ecological Transformations of Society | The education sector's migration *en masse* to online learning during the 2020-21 lockdowns have demonstrated that it can indeed benefit from economies of scale and networking. Online learning will eventually be mainstreamed. Yet, we lack the tools to predict the primary, secondary and higher order ecological impacts and societal transformations that this delivery system migration may result in. (Dr Alexander Flor) | The field is now fertile for futures research and the determination of primary and higher order technological impacts. A significant portion of the academe's research agenda should be devoted to anticipatory studies. (Dr Alexander Flor) |
| Computer Networks and Communication and Mobility | Effective creation of peer-to-peer networks in relation to mobility (e.g. through public transport, traffic signs) and the creation of architectural rules (following universal design principles) that require implementation of networks integrated into buildings without visual impact that support mobility in public spaces. (Dr Marcelo Brites-Pereira) | Point-to-point networks that support mobility integrated, discreetly and in harmony with architecture and aesthetics, in public facilities and buildings that support mobility in public spaces. (Dr Marcelo Brites-Pereira) |
| Cloud Computing, Privacy and Social Surveillance | "Data security and privacy protection are the two main factors of user's concerns about the cloud technology. Though many techniques on the topics in cloud computing have been investigated in both academics and industries, data security and privacy protection are becoming more important for the future development of cloud computing technology in government, industry, and business." (Yunchuan Sun, Junsheng Zhang, Yongping Xiong, and Guangyu Zhu)[7] | "The use of cloud technologies in the educational process is becoming more and more popular and opens up many opportunities, both for educational institutions, teachers, and students… students and teachers can realize learning opportunities practically at any time, not depending on local information and educational resources institutions. As a result, this leads to tremendous time savings. Besides, constant availability removes barriers to access to information for students who are physically unable to attend classes in person." (James Riddle)[8] |

[7] https://journals.sagepub.com/doi/full/10.1155/2014/190903
[8] https://www.computer.org/publications/tech-news/build-your-career/cloud-technologies-in-the-education-system

| | Challenges | Opportunities |
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| Big Data Analysis and Machine Learning | "The fast-growing education industry has developed numerous data processing techniques and AI applications, which may not be guided by current theoretical frameworks and research findings from psychology of learning and teaching. The rapid pace of technological progress and relatively slow educational adoption have contributed to the widening gap between technology readiness and its application in education." (Hui Luan, Peter Geczy, Hollis Lai, Janice Gobert, Stephen J. H. Yang, Hiroaki Ogata, Jacky Baltes, Rodrigo Guerra, Ping Li and Chin-Chung Tsai)[9] | "While it is still the nascent effort to use big data in education, the value of information extracted from big data presents unique, promising opportunities to provide personalized student learning and inform educational policymaking." (Yinying Wang)[10] |
| Power of AI-Methods and Algorithms for Decision-Making | "After all, data give AI sustenance, including its ability to learn at rates far faster than humans. However, the data that AI systems use as input can have built-in biases, despite the best efforts of AI programmers." (John Villasenor)[11] | "According to our review… the most prominent advantage of AI was stated as timely monitoring of learning processes… For example… a sensor-based learning concentration detection system using AI in a classroom environment." (Ismail Celik, Muhterem Dindar, Hanni Muukkonen and Sanna Järvelä)[12] |
| Recognition (Tracking), Enduring Information and Quality of Information | The enormous amount of information that can be generated from neuroscience-based recognition devices may lead to biased or erroneous interpretations of the information. There is likely to be an avalanche of recognition-based research in which the correct interpretation of the data is not supported by scientists competent in neuroscience techniques. (Prof Javier Osorio) | The immense information based on spontaneous neuronal responses, different from that obtained from classical systems based on the evaluation of knowledge, attitudes or skills, can open the door to a better understanding of the educational ecosystem in all its dimensions. The combination of scientific disciplines that converge in recognition techniques will enrich research and subsequent practical application in education in the coming years. (Prof Javier Osorio) |
| Virtual and Augmented Reality | There are issues in discomfort with wearing devices, goggles in particular. Motion sickness is another issue to tackle. (Dr Sonya Yeom) | Training in dangerous and/or expensive domains works well. Sometimes the limits of technology are only at the level of our imagination. (Dr Sonya Yeom) |

9 https://www.frontiersin.org/articles/10.3389/fpsyg.2020.580820/full
10 https://link.springer.com/article/10.1007/s11528-016-0072-1
11 https://www.brookings.edu/blog/techtank/2019/01/03/artificial-intelligence-and-bias-four-key-challenges/
12 https://link.springer.com/article/10.1007/s11528-022-00715-y

| | Challenges | Opportunities |
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| 3D/4D Printing and Energy | I believe that the biggest challenges today are mainly two (on a short and fast resume): the waste of material caused by 3D printing (resulting from failures), and the education and training of children, young adults and adults to be more 'maker', providing them an education for creativity, empowering them with skills (in addition to the existing ones) in the area of 3D design and programming — using the STEAM teaching approach. (Dr Marcelo Brites-Pereira) | I think that in the field of research, opportunities will involve discovering new materials and recycling them. From the point of view of education, we have the opportunity to provide more and more students with conscious and with new skills of knowledge and knowing how to do. And this will, I believe, have a positive impact on the professionals of tomorrow, who are increasingly aware, and with multi- and trans-disciplinary skills. (Dr Marcelo Brites-Pereira) |
| Humanoids and Digital Equity | Socially, we do not have (although we are getting close to) a common understanding of the demographics of disengagement; technically, we need to integrate user experience (UX) improvements effectively with an understanding of those demographics. (Dave Donaghy) | Now that we are beginning to put in place a common acceptance and un understanding of the demographics of disengagement, we can apply humanoid development effort to improve UX at the lower ends of those demographics. A Fellow of the RSA, who worked in end-of-life care at massive disaster events, said that digital technology can provide contact with loved ones for those in the final hours of life; humanoid development might well have some overlap here. (Dave Donaghy) |
| Robotics and Decent Work | Robotics are current been seen in some cases as a threat, both as a threat to jobs and to security. If robotics are to be of value for educational and social purposes in the future, these major challenges will need to be addressed and accepted by those in positions to apply their benefits. (Prof Don Passey) | Already, robotics are being used in some schools, to support a range of educational purposes and needs, including language development and behavioural support. With teacher shortage likely to persist in the future, robotics could provide opportunity to support teachers, rather than to replace them, as is seen in current practice. To meet this prospect, however, technical development will need to consider specific forms of support interaction that will be used. (Prof Don Passey) |
| Ethical Issues of Autonomous Systems | "The recently established techno-economic model inflicts new patterns of work at both intellectual and physical levels, challenging the old-fashioned production norms and producing consistent mistrust… It may thus be argued that automation developments might entail a significantly more pronounced effect on employment than what has ever been recorded before, increasing concerns that mass redundancies will prevail over job creation." (Alexandros Nikitas, Alexandra-Elena Vitel and Corneliu Cotet)[13] | "related to corporate/organisational ethics is the issue of "who decides" about the design and/or operation of a RAS [Robotics and Autonomous Systems]. Ethically, the "obvious" answer is the person or people who might benefit from the RAS, and those who might be put at (greater) risk. Where these groups are the same it is easier to see how to manage the balance between benefits and risks. In many cases, however, there is not such a simple alignment of benefits and risks and/or such a large population is affected by a decision" (Prof. Alan Winfield, Prof. John McDermid, Dr Vincent C Müller, Zoë Porter and Prof. Tony Pipe)[14] |

[13] https://www.sciencedirect.com/science/article/pii/S0264275121001013
[14] https://www.ukras.org.uk/publications/white-papers/ethical-issues-for-robotics/