Key Technologies Shaping the Future

Foresight and strategic recommendations
from a joint conference by

Royal Academy of Engineering

CESAER

17 January 2022

This conference statement was published on 17 January 2022 following the ‘Key technologies shaping the future’ conference which took place from 1 to 2 July 2021 organised jointly by:

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Five take-away messages

Against the backdrop of tremendous local and global challenges ranging from pandemics to climate change, and in the context of rapidly emerging key technologies, which will shape our future, we are currently at a tipping point where complacency is not an option. Our world is rapidly changing and not by default for the better. Therefore, action is needed to ensure we shape our future to be on the right trajectory.

Following the 'Key technologies shaping the future' conference which took place from 1 to 2 July 2021 organised jointly by Royal Academy of Engineering and CESAER, and in combination with targeted interviews with expert contributors, five key take-away messages have emerged.

N.B. 'Europe' in this statement includes all signatory countries of the Council of Europe.

1) Live values

To guide the development of key technologies, reaffirming and adhering to values is foundational.

Actions for university leaders:

- Adhere to, and defend scientific integrity, academic freedom, and institutional autonomy by signing and promoting the *Magna Charta Universitatum*, and live the principles and values and assume the responsibilities described therein.
- Establish policies and procedures to ensure that research, education, and innovation activities related to key technologies support and develop efforts that promote the application of human rights (positive dimension) and never contribute to, nor benefit from, human rights violations (negative dimension).
- Empower people and communities with respect to key technologies by contributing to and making the curriculum in science, technology, and engineering from our best universities freely and digitally available to the world.
- Thought leadership and defence of new disruptive key technologies (some yet to be defined) that can provide major solutions to current societal challenges that can benefit all of humanity.

Actions for leaders in government and policy:

- Defend key values such as democracy, human rights, and freedom of speech against external pressures and challenges.
- Safeguard scientific integrity, academic freedom, and institutional autonomy as described in the *Magna Charta Universitatum*, to enable universities to assume the responsibilities described therein.
- Champion research and education as the engine for positive transformative change, providing the skilled practitioners and shared societal understanding needed as the foundation to achieve healthy, safe, secure and equitable societies and a net-zero world.
- Ensure sustainable funding levels for universities, so the universities can make the curriculum in science, technology, and engineering from our best universities freely and digitally available to the world.

- Enable technology development and implementation of solutions for a net zero world in all countries including the developing world via appropriate donations and charity.

Action for leaders in research funding:

- Ensure research funding decisions align with societal values and empower researchers, engineers and universities to live values.

2) Meaningful leadership must be backed by sustainable funding and long-term commitment

The disruptive potential of key technologies can only be effectively guided with long-term commitments through systems-based and socially inclusive approaches.

Actions for university leaders:

- Support and encourage teachers and researchers in their societal engagement.
- Empower students to understand their societal role so they can assume responsibility.

Actions for leaders in government and policy:

- Ensure sustainable funding for universities.
- Ensure that the 3% of GDP for R&D target is finally achieved as agreed by the European Council in 2002 when the UK was still a member state of the EU (it is currently languishing well below the 3% objective in most countries).

Actions for leaders in research funding:

- Remove undue focus on short-term and narrow indicators (e.g. key performance indicators and rankings) as these act as barriers to change by reinforcing outdated notions around 'what is success'.
- Safeguard balance between bottom-up, investigator-driven frontier research versus top-down, challenge-driven research, including whole system, end to end research.

3) Big data is an unstable foundation

Availability and integration of large-scale data sets and interconnectedness of digital assets are the foundations on which many key technologies (such as artificial intelligence) are based, and today this foundation is fragmented.

Actions for university leaders:

- Defend scientific knowledge and technology (including data and digital assets) as public goods by invoking rights retention on scientific findings to prevent 'siloing' and lock-in to commercial platforms, whilst ensuring effective data and security threat protection and fair value chains for the use of data.
- Actively shape the future of the European and global data landscape, including by contributing to the European Open Science Cloud (EOSC) and joining the EOSC Association.
- Ensure professional data support services, for example by following the rule-of-thumb of employing at least one data steward for every twenty PhD candidates at the university.

- Stimulate the development of projects and initiatives that extract value from the data, with the aim of improving quality of life, process efficiency and institutional strategy, while safeguarding privacy and adhering to the most stringent data safety standards.

Action for leaders in government and policy:

- Develop and implement coherent, clear, and internationally aligned strategies to support the professional management and stewardship of data and digital assets (e.g. to ensure the FAIR principles can be effectively implemented) together with the scientific community.
- Ensure strategies and policies are targeted to increase transparency and building trust in the use and deployment of big data.

Action for leaders in research funding:

- Provide sustainable funding to professional support and infrastructures needed for long-term management and stewardship of data and digital assets.
- Support multidisciplinary projects aimed at the grand challenges of the 21st century, which use and extract value from data and digital assets.

4) Empower researchers to assume their role

Key technologies are shaped by and will shape the global environment, and researchers, learners, and teachers must be empowered to engage globally with their peers.

Key technologies cross disciplinary boundaries and old-fashioned ‘disciplinary siloed, lone-wolf competition’-based approaches must be fully replaced by team-based collaboration at the interface of technology and society and enable effective collaboration to address whole system challenges.

Actions for university leaders:

- Support modern academic careers by (i) endorsing the Hong Kong Principles for Assessing Researchers, and (ii) signing the San Francisco Declaration on Research Assessment or equivalent;
- Conduct institutional self-assessment using the SPACE rubric to assess ability to identify and support potential interventions towards supporting modern academic careers.

Action for leaders in government and policy:

- Safeguard and promote open global cooperation, acknowledging the crucial role of the free circulation of scientific knowledge, technology and its bearers (researchers, learners and teachers) for building bridges between conflicts, countries, continents and cultures, especially when there are political tensions.
- Integrate evidence based analysis in procurement and research funding throughout EU, and ensure a CSO present in all executive councils of governance.

Actions for leaders in research funding:

- Support modern research careers by (i) endorsing the Hong Kong Principles for Assessing Researchers, and (ii) signing the San Francisco Declaration on Research Assessment or equivalent;
- Implement the recommendations on effective funding for inter- and transdisciplinary research.

5) Equality, diversity and inclusion as the foundation for key technologies

To serve society's diverse needs, equality, diversity and inclusion must be an integral part of our work on key technologies, and included in any ethical frameworks.

Action for university leaders:

- Ensure achievement of equality, diversity and inclusion through personal leadership, institutional vigour and societal change, for example following the Declaration on Equality, Diversity and Inclusion at Universities of Science and Technology.

Actions for leaders in government and policy:

- Facilitate continuing conversation with citizens over new technologies and ensure broad efforts to educate and engage with diverse communities;
- Commit to achieving literacy for everyone in key technologies, notably including AI and data literacy.

Action for leaders in research funding

- Revisit research ethics committees to ensure their processes are fit-for-purpose when it comes to AI and data science research and other key technologies.

Message from the Presidents

Modern society has been shaped by the successes of science and engineering and, accordingly, society looks increasingly to science, technology and engineering to provide leadership in addressing local and global challenges. However, today's challenges are more complex than ever before and place new demands and expectations on our science and engineering institutions and on our professions. The Royal Academy of Engineering and CESAER have come together to consider the impacts of new technologies, their promise, the potential risks that need to be managed to ensure widespread benefits for society, and the manner in which our institutions and professions should themselves evolve.

Universities, engineers and scientists are being asked to accept wider responsibilities: to educate the future workforce, create jobs and boost economic growth, assume social responsibility, contribute to sustainability, keep knowledge safe and control the flow of scientific knowledge and technology for security reasons.

These expectations bring great responsibility. We are in the midst of deep economic and societal disruptions caused by the rapid adoption of digital technologies and are exposed to the effects of climate change and a global pandemic. If trust breaks down in the face of such challenges, universities, researchers and engineers risk being viewed as part of an elite that is distant from everyday lives and concerns and technology itself may be perceived as a source not of solutions but of threats.

At the same time, our fields of science, technology, engineering, learning and teaching have themselves been transformed by increasing digitalisation and the exponential growth of scientific data. Rapidly developing key technologies such as artificial intelligence, quantum technologies, nanotechnologies and life-science technologies are adding complexities as developments in science and technology are often outpacing political and societal developments. The result is that researchers and engineers can find themselves in uncharted territory with tools of enormous potential but nascent and under-developed guidelines and rules for their use.

In response to these issues we need to quickly develop the societal role of science, technology and engineering. As universities, researchers and engineers, we highlight here three key areas where we as a community need to pay special attention: (i) to break down barriers, (ii) to push the frontier and (iii) to assume responsibility.

First, open global cooperation and competition are vital to our community, as they are foundational for excellence in science, technology and engineering. They allow the best to find each other, work together to solve complex problems and use the best methods and tools available. We must thus engage and collaborate to prevent the formation of barriers, and to remove existing ones, whether between the EU and the UK or with any likeminded global partners. Furthermore, we must continue to work globally with all to maximise our chances of meeting the biggest challenges and to maintain dialogue between nations. Our continent's history has proven that open cooperation and competition are essential to boost excellence, achieve inclusion, and bring peace and prosperity to our societies.

Second, we must renew our efforts to push the frontiers of knowledge, both within and across disciplinary boundaries. Faced with urgent challenges, it may be tempting to argue that we must meet those challenges by redirecting funding away from investigator-driven, frontier research towards politically determined, top-down priorities. Let us be clear, supporting frontier research is not a luxury. It is key to tackling complex issues, for the simple reason that such issues call for novel ideas and thinking beyond the frontier of our knowledge. Many of our most pressing challenges are so precisely because they do not yield to today's understanding and tools.

Third, we must assume responsibility. We, as leaders in engineering, science and technology have a particular responsibility around key technologies and their developments, to prevent harm and to guide government and broader society about the ways in which they can be used for benefit through responsible research and innovation. In doing so we must work with wider societal groups, bringing our values along with our specialist expertise and insight, to inform the co-creation of ethical frameworks. Our ability to do this rests upon academic freedom and institutional autonomy for universities, which are fundamental to meeting all our wider responsibilities to society, including research ethics, scientific integrity and the overarching responsibility to "engage with and respond to the aspirations and challenges of the world", as set out in the *Magna Charta Universitatum*.

While there is much for us as engineers and universities to do, we do not operate in a vacuum. We are ready and willing to assume responsibility and we invite policymakers and funders in the EU, UK, all of Europe and globally to join us!

Professor Sir Jim McDonald *FRSE FREng FInstP FIET*
President of Royal Academy of Engineering
Principal and Vice-Chancellor of the University of Strathclyde

Professor Rik Van de Walle
President of CESAER
Rector of Ghent University

Message from the Editors

The thirtieth anniversary of CESAER and the forty-fifth anniversary of the Royal Academy of Engineering provides a great opportunity to imagine what the world of tomorrow will need, to guide our actions today.

In 2020, the two organisations launched a joint task force consisting of Fellows from the Academy and representatives from CESAER Members, led and supported by the undersigned. The objective of the joint task force was twofold, i.e. to (i) imagine a desired future in 30 years (foresight) and (ii) explore how we should act now to mitigate risks towards ensuring a desired future comes true (strategic recommendations).

The efforts of the joint task force culminated in the international online conference 'Key technologies shaping the future' from 1 to 2 July 2021 (video recordings from the conference are available online). In addition, interviews were conducted with invited experts. This document summarises key conclusions and provides a synthesis of findings from the conference and the interviews and was drafted by the undersigned, with all task force members and contributors invited to further develop and provide feedback to the document before it was endorsed by CESAER and the Royal Academy of Engineering. It is important to note that the foresighting approach of scenario, impact, planning and action used in this statement is focused on identifying risks and mitigation strategies towards actionable recommendations. This is by design. Each of the four themes also come with great opportunities and potential positive impacts, but in the interest of brevity these are only briefly explored in this statement.

Thirty years may sound like a distant future, but if we hope to be prepared for the challenges of the future, we must start now to imagine what's ahead. As leaders in solving problems and innovation, we must look over the immediate horizon, be visionaries, as well as practical, assisting governments and funders as they shape policy for a desired future. The task force established four themes, which were reflected in the four sessions of the conference and the sections of this statement.

The first theme is 'A Healthy Society in 30 Years': A global pandemic has shown us that we need to carefully consider how key technologies will shape future health systems, including public health. We face the urgent need for a resilient healthcare system to prepare for another pandemic, while also embedding effective care for our aging population. We will turn to technology for solutions. The year before the first case of Covid-19 was identified, mRNA vaccines were heralded as 'a new era in vaccinology'. Less than two years later billions of Covid-19 vaccines based on mRNA technology have already been administered. But recent months have also proven that technology and science are only half the story: we must call upon the social sciences to advise us on cultural and behavioural insights as we seek to mass rollout technological solutions, not least reflected in the vaccination process.

The second theme is 'A Safe, Secure and Equitable Society in 30 Years': We see the pace accelerating for artificial intelligence, robotics and cybersecurity even as there are increasing calls for an ethical reckoning. In parallel, as the pandemic closed down much human activity or forced it online to the financial and social detriment of many, some benefited greatly. The pandemic has also put a spotlight on the digital divide in access to education. Equal access to technology therefore must be the foundation for an equitable, safe and healthy future. Ensuring that key technologies serve society as a whole, and instilling this as a foundation in everything we do, is and remains a key objective.

The third theme is 'Net Zero World in 30 Years': To avoid the worst damages from climate change, we must achieve net-zero carbon emissions by 2050, as reported by IPCC. This is of course a massive undertaking as the world today is still substantially powered by carbon. To change this, a whole systems approach is necessary. It must involve concurrent, coordinated transformation of multiple interconnected infrastructure systems, combining local, national, and international levels. Scientific and technological breakthroughs will be instrumental, especially when coupled with behavioural and cultural changes.

The fourth theme is 'Envisioning Learning and Teaching in 30 Years:' As we have seen, the pandemic highlighted the digital divide in access to education and training. This clearly shows that when science and technology change society, they must change it fairly for everyone or we will simply see new ecological, economic and social problems take root. Virtual learning and remote teaching are no longer fringe activities, and the speed of innovation in blended learning will continue to accelerate. Technologies such as augmented and virtual reality, artificial intelligence, 5G and Internet-of-Things will help to make the blend of the physical and virtual experiences more seamless. We need to harness the power of digital technologies to support collaboration and peer-to-peer learning as well. Yet we should remember that not just technology, but equal access to technology, must form our foundation.

The next thirty years will hold no shortage of challenges. Some will be familiar, while others will be entirely new.

Let us stay optimistic as we work together to shape the future for the better.

Finally, we extend our deepest gratitude to all task force members and invited speakers and contributors for all their efforts, and to the Royal Academy of Engineering and CESAER for their trust and support.

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Deputy Secretary General
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Healthy Society in 30 years

Each of the four themes on this and the following pages provide a synthesis of the discussions during the conference, with the task force and from interviews with invited contributors.

Examples of key technologies

- Artificial intelligence
- Robotics
- Machine learning
- Sensors
- Big data (e.g. gene expression data already existing today)
- Augmented reality (AR) and virtual reality (VR)
- Biotechnologies
- Neuroengineering and Neurotechnology

Scenario

Forecast of what the world will look like in 2050 if we follow our current trajectory.

Everything that can be automated, will be automated.

We will be able to integrate diverse and multisource information to have a much better view of the health of each individual and predict the future trajectory of personal wellbeing and health.

Patient-doctor interactions where patients interact directly with artificial entities will be the norm.

Today, artificial systems are working on association and correlation. In the future we are moving towards AI-systems being able to establish causality and execute counterfactuals. This capability will be a gamechanger in terms of capacity and ability for medical diagnosis and exploring and guiding treatment options.

Average life expectancy for someone born in 2050 will exceed a century.

In drug development a key development is the integration of artificial intelligence and miniaturized systems (e.g. lab-on-a-chip). Innovation will become largely disconnected from serendipity, and instead based on engineering-approaches. Miniaturized systems will complete development and testing cycles based on machine learning algorithms. Similar to AlphaGo and AlphaFold today, these types of systems will play out 'what if' scenarios and train and develop based on this. Experimental planning and execution will therefore be done by artificial intelligence connected to closed-loop miniaturised systems.

Entertainment industry developments will be integrated with the health sector, e.g. AR and VR with complete immersement where you can both 'see and feel' in artificially generated environments (e.g. place-independent surgeries or for medical teaching) or to control artificial limbs for patients.

Impact

Consequences of following the trajectory.

Technology-enabled systems, like humans, are not perfect, and we need to build in safeguards and quality control.

Truly personalised precision medicine will become reality.

Decision-making in a range of sectors will be disrupted by the ability to predict long-term health outcomes (e.g. you will get this rare disease in a few decades).

The ability to predict and direct long-term individual health outcomes may create additional layers of interdependence, which if not governed properly may result in individuals having reduced independence.

With century-long life spans, retirement ages need to be adapted.

Advanced technologies risk creating ballooning costs of medicine.

Information overflow and risk for increased bias: We may start to use AI systems to create reports and summaries of scientific information, and if they are biased and imperfect this may create unforeseen consequences. Today, every researcher has bias, blindspots and misunderstandings which are unknown to them, but crucially they vary from researcher to researcher. If we increasingly depend on automated systems, then these systems may in the worst case create blind spots or misunderstandings across whole sectors of the research community.

Planning

Strategies which should take priority towards achieving any desired change in trajectory.

Proper and well-informed integration of information depends on well-organised data sets, ensuring deployment and implementation of data strategies for data management and stewardship is vital (e.g. based on FAIR principles).

We must prevent unintended lock-in of information into siloes (e.g. with individual commercial actors).

Change happens at the 'rate of trust,' and building trust with the broader society is therefore vital. This is a continuous process which is executed most effectively through transparency and engagement. Lessons can be learnt from parts of entertainment industry which does this effectively with pull-and-push cycles that reinforce each other.

Action

Recommended actions

University leaders

- Ensure institutional strategy for data that guarantees suitable resources, infrastructure, professional support and sufficient level of training of staff and students
- Invoke rights retention on data from their researchers to prevent siloing
- Promote societal engagement and building of trust
- Create environments that facilitate interdisciplinarity across engineering, medicine, and humanities

Research funders

- Fund team science and interdisciplinary research.
- Safeguard a balance of fundamental and applied research, e.g. ensure sufficient support of research at low-TRL levels and prevent undue focus on close-to-market research

Policy makers

- Work closely with researchers and engineers in developing and advancing regulatory frameworks, including in patient privacy
- Remove obstacles to sharing health data while respecting privacy and security

Safe, Secure and Equitable Society in 30 years

Examples of key technologies

- Sensor technologies
- Artificial intelligence
- Quantum technologies
- High-speed communication (6G)

Scenario

Forecast of what the world will look like in 2050 if we follow our current trajectory.

Routine deployment of algorithmic decision-making in all aspects of public life.

Quantum technologies and encryption systems will be fully deployed in some countries and global regions.

Ubiquitous network of sensors and cameras covering land, sea and space from the micro- to the macro-level.

High-speed communication technologies enabling interconnection and integration of virtually all devices and sensors.

Impact

Consequences of following the trajectory.

New capabilities (through quantum technologies etc.) in healthcare, more efficient industrial processes and more efficient mobility through better planning.

Continuing concentration of wealth to a few individuals, to the detriment of many nations and large populations of people.

Exacerbation of current inequalities as large groups are poorly served, or even excluded or marginalised, by AI-based decision systems.

Serious cyber-security risks for nations which do not have access to the latest security and computing technologies as post-quantum computing systems make current security obsolete.

Disappearance of privacy as availability of audio-visual and other sensory data overwhelms ability to anonymize.

Unsustainable energy consumption, e.g. through deployment of blockchain technologies without consideration of energy sustainability and proportionality.

Planning

Strategies which should take priority towards achieving any desired change in trajectory.

Embrace collaborative approach with a foundation around building trust to improve ethical technology development. This includes understanding expectations around how people want technologies to shape their lives and ensuring diverse societal representation in the governance of technologies and their deployment.

Investment in a broad range of technical, social science and humanities disciplines, to create the skilled practitioners who can enable this interdisciplinary approach.

To augment AI research, we must focus on (i) data set provenance, (ii) quality of data, (iii) representation in data sets and acknowledgement and mitigation of biases in inputs and outcomes

Better and forward-looking regulation should focus on being (i) agile and responsive, (ii) protecting individuals from harm and (iii) ensuring technologies are ‘sandbox tested’ under controlled conditions before public deployment

Action

Recommended actions

University leaders

- Empower students to understand their societal role so they can assume responsibility.
- Revisit research ethic committees to ensure their processes are fit-for-purpose when it comes to AI and data science research.
- Invest in training the people who will train the future leaders, users and developers.

Research funders

- Enable long-term, collaborative team science.
- Incentivise interdisciplinary research.
- Increased support for socio-technical systems and approaches.
- Make funding contingent on ensuring there are suitable institutional frameworks around ethics, governance and impact of new technologies.

Policy makers

- Rethink governance and regulation in a way that is future-proof, thinking long-term.
- Scale up and commit to a 10-year programme of high-level AI skill-building.
- Commit to achieving AI and data literacy for everyone.
- Facilitate continuing conversation with citizens over new technologies and a broad effort to educate and engage with diverse communities.

Net Zero World in 30 years

Examples of key technologies

- Solar cells
- Batteries
- Smart distributed grid
- Basket of low carbon energy generators incl. wind, hydrogen
- Carbon sequestration
- Advanced materials including for low- and no-loss energy transmission
- AI and Robotics

Scenario

Forecast of what the world will look like in 2050 if we follow our current trajectory.

Global surface temperatures increase by over 1.5°C versus pre industrial levels, current projections suggest at least a 2°C increase by 2050.

We will fail to reach net-zero by 2050 and we will fail to achieve the goal of the Paris agreement.

Impact

Consequences of following the trajectory.

'Why is it necessary and even vital to maintain the global temperature increase below 1.5°C versus higher levels? Adaptation will be less difficult. Our world will suffer less negative impacts on intensity and frequency of extreme events, on resources, ecosystems, biodiversity, food security, cities, tourism, and carbon removal.' Quote from and full details in IPCC Special Report Global Warming of 1.5 ºC.

Planning

Strategies which should take priority towards achieving any desired change in trajectory.

Net zero cannot be achieved by throwing money at the problem and deploying conventional approaches. It must involve concurrent, coordinated transformation of multiple interconnected infrastructure systems. A whole systems approach on local, national, and international scales.

A systems approach is:

- Rapid and simultaneous transformations
- Allowing integration of all relevant factors in suitable proportions into decision making
- Support evidence based decision making across multiple areas of policy
- Co-benefits can be recognised and enabled
- Enables the identification of low-regret decisions
- Avoids the risks of unintended consequences

Mapping of interdependencies and interactions is vital.

We need to start triggering 'low-regret' options already today using system thinking to identify early wins which won't work against us later.

On the energy supply side we should move from large scale monolithic power systems (e.g. coal power plant) to modular and distributed generation (e.g. solar and wind distributed across society).

On the demand side substantial efforts are needed to work towards the societal changes needed in domestic and housing sector (e.g. energy consumption for heating), transportation sector (e.g. electrical vehicles) and industrial sector (e.g. from sourcing of materials through manufacturing to consumption).

High levels of electrification are key enabler of decarbonisation where the electricity demand is met by renewables. Green interconnectors used to balance supply and demand where possible.

Storage and flexibility is crucial, especially in the light of increasing electricity demand and the peaks and troughs inherent to many renewables. High deployment of offshore wind and solar as 'workhorse', supported by marine and geothermal.

Smart local grids with AI supported decision making to optimise demand needs with green energy supplies for a distributed energy basket across nations.

Action

Recommended actions

University leaders

- Empower students to be engines of change
- Lead by example through carbon-neutral campuses and operations
- Act as the nodes for change with regional leadership and example
- Promote inter and transdisciplinary research which underpins systems thinking and approaches

Research funders

- Fund inter and transdisciplinary research which underpins systems thinking and approaches
- Ensure best practises developed locally are available globally
- Open innovation and publications

Policy makers

- Ensure bold ambitions and swift implementation of key initiatives such as the European Green Deal and Reaching Net Zero in the UK
- Remove barriers to the free international circulation of researchers, scientific knowledge and technologies as national boundaries are meaningless for tackling global climate
- Remove barriers to ensure smooth and rapid planning procedures for constructing research and pilot plants for solar power
- Ensure effective cross sector / cross department research priorities and support integration, e.g. transport and power, planning and buildings.
- Ensure appropriate incentives for industry to support societal beneficial research via procurement and policy change
- Regular GDP fractional support for R&D in Net Zero locally and globally

Envisioning Learning & Teaching in 30 years

Examples of key technologies

- AI and robotics
- Interactive and immersive technologies, virtual reality (VR) and augmented reality (AR)
- Science of learning
- Quantum computing

Scenario

Forecast of what the world will look like in 2050 if we follow our current trajectory.

Learning and teaching will be online, modular, personalized, interactive, immersive and global.

A foundation will be integrated AI-driven human-machine learning environments. The result is truly personalised learning adapting to each individual underpinned by AI, advances in (quantum) computing and cognitive science.

Learners will have life-long relationships with their universities for upskilling or to learn something new. To advance in their career, shift careers or even just for curiosity.

Short and modular programmes. As pace of change accelerates learners demand short, future-proof programmes.

Blended learning on campus. Covid-19 led to all-online but over time this will stabilize around hybrid online and on-campus to get the best of both worlds.

Embodied cognition (coupling of mind and body for learning and teaching) underpinned by the convergence of biology, engineering (including VR and AR) and cognition sciences ensures multi-modal encoding of information (i.e. more effective and long-term learning outcomes).

Impact

Consequences of following the trajectory.

Our ability and capacity to tackle complex challenges will critically depend on successfully evolving and adjusting education practice (e.g. one-to-all in lecture hall or zoom call) towards personalised learning and learning environments.

Higher education institutions which embrace this change will help lead the way, others will become obsolete.

Establishing life-long engagement and learning between higher education institutions and broader public engenders trust in scientific knowledge, empowers individuals across all of society to explore and develop, and act as shock absorbers when technologies disrupt sectors and springboards for individuals into new professions and sectors.

Planning

Strategies which should take priority towards achieving any desired change in trajectory.

Research-based education is the bedrock for transformative change, and provides the skilled practitioners and shared societal understanding needed as the foundation to achieve healthy, safe, secure and equitable societies and a net-zero world.

Big technological drivers, including the key technologies identified in this conference statement, need to be considered and included in the design of curriculum and development of research-based educational practice.

The rate-limiting step in the change towards our desired future is culture (not technology), that is the foundational transformation we need to make.

Reconnect teaching and research as inseparable (as laid down in the MCU), where research should relentlessly challenge and inform what is taught and how, and learners and teachers should directly engage with research in their development.

Put learners and their experience at the centre including by structural and systemic involvement in decision-making processes.

Increase awareness of issues around inclusion and privilege. Concerted efforts are needed to remove the digital divide (e.g. "Pay the wi-fi or feed the children": Coronavirus has intensified the the world's and UK's digital divide)

Take a 'whole-pipeline approach' where girls and children from all backgrounds are invited and encouraged to pursue studies in science, technology and engineering, notably by cultivating interest and competencies and by building capacity.

Embrace whole person learning and teaching which is academic, professional, emotional and supports mental health and wellbeing and recognises the need for community.

Action

Recommended actions

University leaders

- Work with the university community to create cross-departmental and cross-school academic initiatives and help remove disciplinary barriers and siloes, and also focus on skills.
- Deploy long-term funding for educational innovation at the institutional and school levels that can catalyze transformative change.
- Empower students to be agents of change and create interdisciplinary scientists
- Ensure structural and systemic involvement of student representatives in decision-making processes
- Embrace whole person learning and teaching, where time, space and trust is provided for learners and teachers to explore and develop under low-stress conditions
- Unleash knowledge by making curriculum in science, technology and engineering from our best universities freely available digitally to the world

Research funders

- Ensure funding structures acknowledge and support the inseparable nature of research and education
- Support modern research careers by reducing focus on narrow metrics (e.g. journal impact factors) and put emphasis on education, engagement and outreach
- Provide for long-term, collaborative research projects
- Experiment with diverse funding models to allow researchers to move quickly

Policy makers

- Ensure researchers in the domain of education practice are at the table when advancing educational policy.

- Provide long-term, sustainable funding levels to universities and reduce emphasis on short-term KPIs (e.g. students graduated) to enable curriculum in science, technology and engineering from our best universities to be made available digitally to the world for free. We have the tools for this already today.
- Cultivate interest and competencies and build capacity in primary and secondary school and pre-university settings.
- Prioritize tackling issues around inclusion and privilege, including bridging the digital divide.

Additional resources

- UK AI Council's 2021 AI Roadmap
- Coded Bias (2020 film)
- EU's 2021 proposal for AI regulation
- Beijing AI Principles 2019
- 2020 report Examining the Black Box: Tools for assessing algorithmic systems
- This is Engineering campaign
- European Green Deal
- Reaching Net Zero in the UK
- Geneva Science and Diplomacy Anticipator (GESDA) Scientific Anticipatory Briefs
- The Next 75 Years of Science Policy series from Issues in Science and Technology
- Facial-recognition research needs an ethical reckoning, 2020 editorial Nature
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