The Topol Review

Preparing the healthcare workforce to deliver the digital future

An independent report on behalf of the Secretary of State for Health and Social Care

February 2019

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Contents

Preparing the healthcare workforce to deliver the digital future

Letter to the Secretary of State for Health and Social Care

Dear Secretary of State,

It was a privilege to be asked to lead an independent review to advise on:

- how technological and other developments (including in genomics, artificial intelligence, digital medicine and robotics) are likely to change the roles and functions of clinical staff in all professions over the next two decades to ensure safer, more productive, more effective and more personal care for patients;
- what the implications of these changes are for the skills required by the professionals filling these roles, identifying professions or sub-specialisms where these may be particularly significant;
- the consequences for the selection, curricula, education, training, development and lifelong learning of current and future National Health Service staff.

We are at a unique juncture in the history of medicine, with the convergence of genomics, biosensors, the electronic patient record and smartphone apps, all superimposed on a digital infrastructure, with artificial intelligence to make sense of the overwhelming amount of data created. This remarkably powerful set of information technologies provides the capacity to understand, from a medical standpoint, the uniqueness of each individual – and the promise to deliver healthcare on a far more rational, efficient and tailored basis.

From late 2017 to the present, our cross-disciplinary team of experts, including clinicians, educators, ethicists, computer scientists, engineers and economists, reviewed the available data and projected into the future what impact these technologies would have on the NHS workforce over the next two decades. Such an undertaking with experts from multiple disciplines and a country-wide perspective has not, to our knowledge, been undertaken previously.

The Review has been predicated on the following pre-suppositions:

1. The patient must be considered to be at the centre when assessing and implementing any new technologies.
2. There is remarkable potential for digital healthcare technologies to improve accuracy of diagnoses and treatments, the efficiency of care, and workflow for healthcare professionals, but implementation must only be carried out when there has been robust clinical validation.
3. Patients who are willing to take greater charge of their care using digital tools and algorithms will be empowered, but this should always be an opt-in choice for them.
4. A marked improvement in the patient-clinician relationship is possible, owing to the gift of time delivered by the introduction of these technologies. This will bring a new emphasis on the nurturing of the precious inter-human bond, based on trust, clinical presence, empathy and communication.
5. The new medicine as envisioned will require extensive education and training of the clinician workforce and the public, with cultivation of a cross-disciplinary approach that includes data scientists, computer scientists, engineers, bioinformaticians, in addition to the traditional mix of pharmacists, nurses and doctors.

There are, of course, considerable uncertainties in projecting anything, no less such a precious part of our lives – our health. There are three noteworthy changes that we expect to take hold: a much greater proportion of the population will have their genome sequenced; the empowerment of individuals who will increasingly be generating their own health data with the help of algorithms to interpret that data; and a marked improvement in the speed, accuracy and scalability of medical data interpretation afforded by artificial intelligence, which will provide robust support for all types of clinicians. Taken together, this will lead to an evolution of the patient-doctor relationship that we hope can be greatly strengthened, along with the alleviation of burnout that currently affects a significant proportion of clinicians.

Ultimately, embracing and implementing these technologies (including genomics) throughout the NHS, while clearly representing a challenge, is likely to prevent diseases and their complications, and produce an overall improvement in health outcomes.

We offer a number of recommendations for you to consider. These will require early implementation by education providers, as well as by arm's-length bodies and employers on behalf of the NHS, if we are to gain the benefits these digital healthcare technologies offer.

I would like to personally thank your Department for encouragement, my extraordinary Review Board and Panels for their expertise and commitment, Health Education England and the secretariat for their work on the Review, not forgetting all those who shared insights and experience in response to our call for evidence.

Yours sincerely

Eric Topol, MD
Executive VP and Professor, Molecular Medicine, The Scripps Research Institute
Founder and Director, Scripps Research Translational Institute

February 2019

Executive summary

As people live longer, but also with more long-term conditions, there is an inexorable increase in the demand for healthcare.

The workforce is also changing: millennials have new expectations and most people seek a good work-life balance through flexible careers. The NHS Long Term Plan identifies the need for more healthcare workers to respond to this increasing demand. Digital healthcare technologies, defined here as genomics, digital medicine, artificial intelligence (AI) and robotics, should not just be seen as increasing costs, but rather as a new means of addressing the big healthcare challenges of the 21st century.

The UK has the potential to become a world leader in these healthcare technologies and this Review anticipates how technological innovation will impact the roles and functions of healthcare staff over the next two decades. Our review of the evidence leads us to suggest that these technologies will not replace healthcare professionals, but will enhance them ('augment them'), giving them more time to care for patients. Some professions will be more affected than others, but the impact on patient outcomes should in all cases be positive. Patients will be empowered to participate more fully in their own care.

This ground-breaking Review has sought expert opinion from across the UK and overseas. This is the first time that such a wide breadth of expertise has been brought together to anticipate and debate the impact of technological innovation on the NHS workforce.

With patients placed firmly at the centre of our discussions, this report is the culmination of an extensive literature review, interviews, expert meetings and roundtables. We had an overwhelming response to the call for evidence from individuals and organisations, with responses from hundreds of patient representatives, professional groups, industry, education, regulators and national bodies.

Within 20 years, 90% of all jobs in the NHS will require some element of digital skills. Staff will need to be able to navigate a data-rich healthcare environment. All staff will need digital and genomics literacy. This Review is about both the existing and the future workforce. We need to tackle differences in the digital literacy of the current workforce linked to age or place of work.

The next decade presents an opportunity to address data governance and cyber security concerns, agree ethical frameworks and develop NHS staff/organisations to implement genomics and digital technologies in the workplace. The complexity of data governance requirements should not be a reason for inaction. Most importantly, there must be mechanisms in place to ensure advanced technology does not dehumanise care. While automation will improve efficiency, it should not replace human interaction.

This Review proposes three principles to support the deployment of digital healthcare technologies throughout the NHS:

1. Patients need to be included as partners and informed about health technologies, with a particular focus on vulnerable/marginalised groups to ensure equitable access.
2. The healthcare workforce needs expertise and guidance to evaluate new technologies, using processes grounded in real-world evidence.
3. The gift of time: wherever possible the adoption of new technologies should enable staff to gain more time to care, promoting deeper interaction with patients.

Genomics, digital medicine and AI will have a major impact on patient care in the future. A number of emerging technologies, including low-cost sequencing technology, telemedicine, smartphone apps, biosensors for remote diagnosis and monitoring, speech recognition and automated image interpretation, will be particularly important for the healthcare workforce.

What does this mean for patients, carers and the wider community?

In the future, many aspects of care will shift closer to the patient's home, while more specialised care is centralised into national or regional centres. The NHS has been working towards a less paternalistic relationship between patients and staff for some time, and digital healthcare technologies have the potential to speed up that process, to empower individuals to be more informed about their care, and to allow them to work together with healthcare staff to make treatment decisions.

Genomics has the potential to transform healthcare with more accurate diagnoses of a broader range of diseases with a genetic basis, and to allow patients to know their likelihood of developing one of these diseases. However, there is a need to develop clear frameworks for healthcare staff to use genomic data in a way that safeguards patient confidentiality, and inspires the support and confidence of citizens and the wider community.

Digital medicine is already changing the way people interact with healthcare. Telemedicine services include telephone triage such as 111 and the ability to have video appointments. Smartphone apps help patients self-manage and order repeat prescriptions. Remote monitoring is changing the way care is delivered. Almost 90% of the population regularly use the internet, yet less than a quarter has so far registered for online services with a GP. The health and care system will need to work with patients to co-create applications of digital technologies which meet their needs.

Using **AI-based technologies**, automated image interpretation in radiology and pathology will lead to faster diagnosis, while speech recognition has the potential to free up more staff time to deliver care. AI will transform patient-generated data into clinically useful information and empower patients to manage their own health or seek appropriate health support. Patient benefit should be the driving force behind AI and robotics design, with new products co-developed with patients from design to implementation.

Advances in healthcare technologies and a greater focus on prevention, health and wellbeing will bring major improvements in patient outcomes. However, it is critical that the healthcare system prepares to adopt any new technologies in a spirit of equality and fairness. A range of social determinants affect health outcomes, and digital health technologies should redress not reinforce inequalities, with particular attention given to vulnerable and marginalised groups.

An evolving health workforce

There is a need to raise awareness of genomics and digital literacy among the health and social care workforce. The latter requires the development of the skills, attitudes and behaviours that individuals require to become digitally competent and confident. The levels of digital literacy, the workforce's awareness of the required capability, access to training and support, and skills to enable patients and citizens to improve health and wellbeing through technology will all need to be improved, as a fundamental shift in the balance of skills in the workforce takes place over the next two decades. This will present new career opportunities for some of the workforce.

Genomics will become integral to all medical specialties. While some aspects will remain with highly specialised professionals, many will become mainstream and embedded in routine healthcare delivery. The health workforce will play a key role in ensuring that genomic technologies are efficiently, appropriately and equitably deployed, so that individuals can understand how genetics can affect their health.

Digital medicine will require leadership with the capability to direct the agenda, which should include a Board-level member, as well as new senior roles with responsibility for advising boards on digital technologies. The NHS must build skills in data provenance, curation and governance, enhance the understanding of ethical considerations and strengthen the necessary skills to carry out critical appraisal.

Artificial intelligence will be deployed to augment the skills of the NHS workforce. Staff will need to understand fully the issues of data validity and accuracy. Early benefits of AI and robotics will include the automation of mundane repetitive tasks that require little human cognitive power, improved robot-assisted surgery and the optimisation of logistics.

NHS organisations should invest in their existing workforce to develop specialist skills, including the assessment and commissioning of genomics and digital technologies. With all new technologies, it is essential to identify future champions early and create networks to enable collaborative learning. Accredited continuous professional development (CPD) and flexible on-going training and career opportunities, including portfolio careers in academia or industry, will be important to deliver change. NHS Boards should also take responsibility for effective knowledge management to support innovation and change.

Health service leadership to integrate and adopt new technologies

Technological innovation will increasingly shift the balance of care in the NHS towards more centralised highly specialised care and decentralised less specialist care. This will result in long-term shifts in patterns of need and services. For new digital healthcare technologies to reach their full potential and deliver significantly better patient outcomes without the need to increase resources, the whole health and care system will need to anticipate and plan for the future. As it can take up to 10 years to realise cost savings, investment in IT systems, hardware, software and connectivity, as well as the training of healthcare staff and the public, will have to be planned carefully.

As we shift towards whole genome sequencing, genomics will extend beyond rare diseases and cancers, producing benefits in prevention and management of common later-onset diseases. It is now possible to make corrections to an individual's DNA that could lead to cures for previously untreatable diseases and deliver targeted therapies. Such an intervention may replace some current palliative therapies in the next 10-20 years, achieving cures and having the potential to reduce the costs of chronic treatments.

There is a need to complete the digitisation and integration of health and care records if the full benefits of **digital medicine** (earlier diagnosis, personalised care and treatment) are going to be realised for the NHS. An understanding of how data-driven technologies are best deployed to support and improve working practices will be part of workforce development. This will make it easier to commission digital medicine services, for example, telemedicine with the aim of improving ease of access and decreasing non-attendance rates, or remote monitoring with the aim of reducing unplanned hospital admissions.

Advances in mathematics, computing power, cloud computing and algorithm design have accelerated our ability to analyse, interpret and make decisions using artificial intelligence. Uneven NHS data quality, gaps in information governance and lack of expertise remain major barriers to the adoption of these advances. A binding code of conduct and a transparent information governance framework are required to support the analysis of anonymised patient data by industry, as well as guidance to support the evaluation and purchasing of AI products. Capability must be developed within the NHS to identify and understand algorithmic bias and ensure that data does not reflect the bias inherent in social structures, and reinforce structural discrimination and inequalities.

To ensure equity in the adoption of any new technologies, health economy-led mapping of access, use and impact of technology-enabled care will be essential. Patient safety should be at the centre of the integration of new technologies. Health leaders will need to work together with regulators to review the regulation and compliance requirements of new digital technologies, alongside cyber security and data privacy to ensure transparent, resilient, robust and legally enforceable governance policies and practices, and provide evidence-based guarantees of the safety of healthcare technologies. We should learn from other industries and international examples. Training should be commissioned to develop a cadre of specialists in the regulation and assessment of digital technologies.

In order to bridge the skills gap, the NHS will need to collaborate with academia and industry, and attract global technical talent through new apprenticeships and Masters schemes, for example, expanding the NHS Digital Academy, and introducing industry exchange networks to facilitate collaborative working. There is a need to develop a continuous pipeline of robotics engineers, data scientists and other technical specialists, who can then be attracted into the NHS to create the new technological solutions that will improve care and productivity.

Creating a culture of innovation and learning will be critical, by cultivating a reputation for training and support, proactive learning activities, opportunities to learn and reflect away from the workplace, dissemination of lessons from early adoption and sharing examples of best-practice evidence-based initiatives.

Conclusions

This is an exciting time for the NHS to benefit and capitalise on technological advances. However, we must learn from previous change projects. Successful implementation will require investment in people as well as technology. To engage and support the healthcare workforce in a rapidly changing and highly technological workplace, NHS organisations will need to develop a learning environment in which the workforce is given every encouragement to learn continuously. We must better understand the enablers of change and create a culture of innovation, prioritising people, developing an agile and empowered workforce, as well as digitally capable leadership, and effective governance processes to facilitate the introduction of the new technologies, supported by long-term investment.

Recommendations

The Review Board recommends:

The citizen and the patient

- In a similar way to other public health education initiatives, programmes aimed at engaging and educating the public about genomics and digital healthcare technologies should be developed. (P1)
- The NHS should work with patient and carer organisations to support appropriate patient education. (P2)
- Local arrangements should be established to provide needs-based targeted education and support through existing patient support provision, where possible. (HI1)

The Genomics Panel recommends:

The citizen and the patient

- The NHS, in partnership with relevant regulatory bodies, should establish a clear, robust framework by which healthcare professionals use genomic data, which safeguards patient confidentiality, and inspires the support and confidence of citizens and the wider community. (G1)

Healthcare professionals

- All healthcare professionals should receive core training in genomic literacy to help them understand the basis, benefits and ethical considerations associated with genomics. (G2)
- Lifelong training should be available to healthcare professionals with emphasis on continuing support in this rapidly evolving field, including access to dynamic 'just-in-time' digital updates and online genomic information resources. (G3)
- Accredited genomic training for healthcare professionals should be established in key clinical specialities to incorporate genomic testing and genomic counselling into their practice. (G4)
- Capacity should be built within the NHS Genomic Medicine Service through support for specialist healthcare professionals including genomic counsellors, clinical scientists and specialists in genomic medicine. (G5)

Health system

- An attractive career pathway should be developed for bioinformaticians, including expansion of Higher Specialist Scientist Training for clinical bioinformaticians. (G6)
- A framework for genomic leadership should be developed across clinical specialities and primary care settings to encourage and disseminate best-practice and to simplify patient referral systems. (G7)
- Academic institutions should ensure genomics and data analytics are prominent in undergraduate curricula for healthcare professionals, and that there should be expansion of undergraduate capacity in genomics, bioinformatics and data science. (G8)

The Digital Medicine Panel recommends:

The citizen and the patient

- NHS online content should be a vital trusted source of health information and be resourced appropriately. (DM1)
- The NHS should expand research and development programmes, working closely with patients to co-create digital technologies and ensure that emerging technologies meet their needs. (DM2)

Healthcare professionals

- NHS organisations should invest in their existing workforce to develop specialist digital skills, including the assessment and commissioning of digital technologies, through the Digital Academy, continuous professional development (CPD), sabbaticals and secondments. (DM3)

Health system

- The NHS, working with regulators, should develop and commission courses to increase the number of specialists in the evaluation and regulation of digital technologies. (DM5)

The Digital Medicine and AI & Robotics Panels recommend:

- The NHS should create or increase the numbers of clinician, scientist, technologist and knowledge specialist posts with dedicated, accredited time, with the opportunity of working in partnership with academia and/or the health tech industry to design, implement and use digital, AI and robotics technologies. (DM4/AIR5)

The AI and Robotics Panel recommends:

The citizen and the patient

- The NHS should ensure that patients are involved from the beginning in the design and implementation of AI software for healthcare, with their needs and preferences reflected in the co-design process. (AIR1)

Healthcare professionals

- Educational resources should be developed to educate and train all healthcare professionals in: health data provenance, curation, integration and governance; the ethics of AI and autonomous systems/tools; critical appraisal and interpretation of AI and robotics technologies. (AIR2)

Health system

- The NHS should leverage its global reputation and integrated datasets to attract skilled experts from the global community of data scientists. (AIR3)
- Given the national shortage and competition for AI specialists, there should be a national programme of 'Industry Exchange Networks' that would benefit the NHS. (AIR4)

The Organisational Development Working Group recommends:

The citizen and the patient

- NHS organisations must ensure that patients, citizens and staff are involved in the co-design of transformation projects, particularly in identifying how digital healthcare technologies can help to improve both patient experience and staff productivity. (OD1)

Healthcare professionals

- Senior roles should be developed with responsibility to advise on the opportunities offered by digital healthcare technologies and identify local skills gaps. (OD2)
- Healthcare professionals will need to access training resources and educational programmes in digital healthcare technologies to assess and build their digital readiness. (OD3)

Health system

- Each organisation should assign Board-level responsibility for the safe and effective adoption of digital healthcare technologies at scale, with a focus on clinical outcomes and on promoting effective and consistent staff engagement. (OD4)
- NHS Boards should take responsibility for effective knowledge management to enable staff to learn from experience (both successes and failures) and accelerate the adoption of proven innovations. (OD5)
- The NHS should strengthen systems to disseminate lessons from early adoption and share examples of effective, evidence-based technological change programmes. (OD6)
- NHS organisations should use validated frameworks to implement technological solutions and ensure staff are trained to use these. (OD7)
- The NHS should support collaborations between the NHS and industry aimed at improving the skills and talent of healthcare staff. (OD8)
- The NHS should work with stakeholders across sectors to review the regulation and compliance requirements for new digital healthcare technologies, including the provision of guidance and training on cyber security, data privacy and data anonymisation, learning from the experience of other international healthcare systems. (OD9)

Educational recommendations to support a digitally enabled health system

Culture of learning

NHS organisations will need to develop an expansive learning environment and flexible ways of working that encourage a culture of innovation and learning. To do this:

- NHS organisations will need to: have a strong workplace learning infrastructure; cultivate a reputation for training and support; develop learning activities which are proactive rather than reactive; allow staff dedicated time for development and reflection on their learning outside of clinical duties. (E1)
- Each NHS organisation should adopt a multi-professional learning collaborative approach supporting staff to learn about genomics and digital technologies. (E2)

Supporting the educators

Delivering the education and requirements of the NHS workforce over the next five years will be challenging. In order to achieve this:

- The NHS and local organisations should support the development of a cadre of educators and trainers who can lead the educational programme to ensure timely upskilling of the NHS workforce. (E3)
- These organisations also need to put in place systems to identify and develop talented, inspiring new educators within the workforce. (E4)

Education and development of the whole workforce

Staff should have the opportunity to access information about genomics and digital technologies adopted by the NHS and develop the necessary skills. To achieve this, within five years:

- HEE should establish a new NHS Digital Education Programme to oversee the implementation of a national digital education strategy. The programme will complement the Genomics Education Programme. (E5)
- Employers must ensure that support for staff to develop and enhance digital literacy is built into training programmes, career pathways and placements. (E6)
- Professional, Statutory and Regulatory Bodies (PSRBs) and practitioners need to identify the knowledge, skills, professional attributes and behaviours needed for healthcare graduates to work in a technologically enabled service, and then work with educators to redesign the curricula for this purpose. (E7)
- Organisations responsible for employing and training must ensure that current and new staff are supported to reach an appropriate level of digital literacy for their career stage. (E8)

Specialist workforce and specialist teams will be working at the very forefront of their disciplines, often being early adopters of new technologies. Supporting these individuals and teams will be important for continued innovation. To support specialists and specialist teams in genomics, digital medicine, AI and robotics:

- For both existing and new roles addressing skills gaps in clinical bioinformatics, digital technologies, AI and robotics, the NHS should develop or expand both educational programmes (for example, the Higher Specialist Scientist Training) and attractive career pathways. (E9)
- The NHS should commission flexible and responsive training for specialist roles. This may include engaging with industrial learning organisations and developing placements, exchanges and secondments. (E10)
- The NHS should work with PSRBs and other bodies to introduce and strengthen accreditation of newer specialist groups. (E11)

Educating the future workforce

Within five years, we need to make sure that the education and training for future employees equips them to achieve their full potential as staff in the technology-enhanced NHS. To equip the future workforce:

- Education providers should ensure genomics, data analytics and AI are prominent in undergraduate curricula for healthcare professionals. Future healthcare professionals also need to understand the possibilities of digital healthcare technologies and the ethical and patient safety considerations. (E12)
- Education providers must ensure that students gain an appropriate level of digital literacy at the outset of their study for their prospective career pathway. (E13)
- Education providers should both offer opportunities for healthcare students to intercalate in areas such as engineering or computer science, and equally attract graduates in these areas to begin a career in health, to create and implement technological solutions that improve care and productivity in the NHS. (E14)

> Extraordinary accomplishments, from dissecting and defining DNA to creating such pervasive electronic technologies that immediately and intimately connect most individuals around the world, have unwittingly set up a profound digital disruption in medicine. Until now we did not have the digital infrastructure to even contemplate such a sea change in medicine. And until now the digital revolution has barely intersected the medical world. But the emergence of powerful tools to digitise human beings with full support of such infrastructure creates an unparalleled opportunity to inevitably and forever change the face of how healthcare is delivered.[1]"

Dr Eric Topol

1.0 Introduction

On the whole, people in the UK are healthier, wealthier and live longer today than 30 years ago.[2] Yet, in common with other healthcare systems, the National Health Service (NHS) is having to address increasing demand in the context of financial constraints.[3]

This Review has considered how digital healthcare technologies, encompassing genomics, digital medicine, artificial intelligence (AI) and robotics, could enable the NHS to meet this challenge. These technologies already empower patients to participate actively in their own care, with a greater focus on wellbeing to prevent disease such as cancer and cardiovascular diseases. It is also possible to predict individual disease risk and to personalise the management of long-term conditions such as diabetes and asthma.[4] Patients are embracing new technology across most aspects of their lives and increasingly expect their healthcare to be supported by it.[5] However, realising this potential depends on the technology being easy and intuitive to use, meeting a clear need, and being endorsed by healthcare professionals.

This report brings to life the excitement of the opportunities ahead, presenting case studies from today's NHS and scenarios for the future. It addresses the implications for the education and training needs of the current and future workforce. It presents a set of recommendations designed to enable the NHS to harness technological innovation for the benefit of patients, citizens and staff.

1.1 Conducting the review

In 2017, Mr Jeremy Hunt, former Secretary of State for Health and Social Care, invited Dr Eric Topol to lead an independent review to consider and advise on the following:

- How technological innovation (genomics, digital medicine, AI and robotics) and other developments are likely to change the roles and functions of clinical staff in all professions over the next two decades to deliver more effective and more personal care for patients.
- The implications of these changes for the workforce skills required, identifying those professions or sub-specialisms where the changes may be particularly significant.
- The consequences for the selection, curricula, education, training, development and lifelong learning of current and future NHS staff.

Dr Topol appointed a Review Board and three Expert Advisory Panels – on genomics, digital medicine, and AI and robotics. Each was co-chaired by distinguished leaders in the field. Each Panel included a member of the HEE Patient Advisory Forum. A working group focused on organisational development. HEE provided the secretariat team to facilitate the Review (see Appendix 1). Dr Topol said:

> To my knowledge, this is the first time on the planet that such an array of subject matter experts has assembled in one room to focus on the implications of technological innovation in healthcare for the education and development of the workforce.[6]"

The Review also benefited from the input of experts drawn from many disciplines, including behavioural science, bioethics, computer science, education and medical training, engineering, healthcare science, health economics, health informatics, knowledge management, medicine, nursing, pharmacy and public health, as well as members of HEE's Patient Advisory Forum.

This report complements several major reviews initiated to shape thinking on the workforce strategy[7] required to deliver the NHS Long Term Plan.[8]

1.2 Principles

The Review proposes three principles to guide future workforce strategy in relation to the implementation of digital healthcare technologies:

i) Citizens, patients and carers: Technology offers the potential to reshape health and care, empowering people, who are willing and able, to become more actively engaged in their health. For this to be successful, patients, carers and the public must be included as partners in their own care and education. It is critically important that these technological changes do not exacerbate inequalities in healthcare. Therefore, the NHS should prioritise education for citizens, patients and carers alongside the education of the healthcare workforce.

ii) Evidence: The adoption of digital healthcare technologies should be grounded in compelling real-world evidence of clinical efficacy and cost-effectiveness, followed by practical knowledge transfer throughout the NHS.[9] The workforce needs expertise, standards and guidance to evaluate technology applications.[10] A fit-for-purpose, legal and ethical governance framework that patients, public and staff can trust is required.

iii) The gift of time: Whenever possible, the adoption of technology should be used to give healthcare staff more time to care and interact directly with patients. This is critical to enhance the patient-clinician relationship, and improve the patient experience and patient safety. This is also likely to improve the wellbeing of the healthcare workforce.

1.3 Gathering the evidence

This Review sought out expert opinion from a broad range of stakeholders. Panels have considered evidence from a desk review of the available literature, one-to-one interviews and meetings with experts, visits and seven round-table events. These events, two of which focused on mental health, involved 275 participants, including representatives from patients and patient advocacy organisations, professional groups, industry, education, regulators and other arm's-length bodies.

HEE published an interim report in June 2018,[4] launching an online open call for evidence from individuals and organisations with an interest in workforce education and development. This received over 117 submissions, which were reviewed by the Expert Advisory Panels and the Review Board. A separate engagement exercise on mental health provided a supplementary report for the Review Board to consider.[11]

1.4 Prioritising the workforce

On his appointment as Secretary of State for Health and Social Care in July 2018, Mr Matt Hancock highlighted three early priorities for the health and social care system: the NHS workforce, technology and prevention. He said:

> "We need to equip all staff across the NHS with the right skills to constantly innovate and continuously realise the benefits that technology will provide.[12]"

Like many other industries, the NHS is not alone in undergoing such a major change to its service. It is predicted that 90% of all jobs will require some element of digital skills within 20 years.[13] The skills required to navigate a data-rich health environment are much sought after. As a result, there is strong competition to recruit talent with those skills.

For technology to be of maximum value to the NHS, the entire healthcare workforce will need to be supported to work in this technology-enhanced environment. 'Healthcare workforce' in this report is taken to encompass scientific, therapeutic and technical disciplines, as well as managers and commissioners alongside clinical staff. Almost all of the healthcare workforce is likely to be affected and should all be offered the opportunity to develop a broad scope of digital and genomic literacy.

Developing the digital and genomic literacy of the existing healthcare workforce is as important as the education and training of those at the start of their careers. HEE's workforce strategy calculates that more than 50 per cent of today's workforce will still be working in the service in 15 years' time and most are, at best, self-taught in digital technology.[7]

The NHS will be recruiting from a pool of young people for whom interaction with technology is second nature.[14] In 2014, England was the first country in the world to mandate the teaching of coding to children at primary and secondary schools, and digital skills are increasingly embedded in the education of school children.[15] Andreas Schleicher, Director for Education and Skills at the Organisation for Economic Co-operation and Development, said:

> "We have to prepare students for jobs that have not yet been created, technologies that have not yet been invented and problems that we don't yet know will arise.[16]"

While some technological advances already impact on ways of working, the full potential of many developments are as yet unknown and will take time to come to fruition. This 'time-lag' provides an opportunity to invest in the necessary training and support to allow the current healthcare workforce to embrace technological innovation.

This Review, therefore, seeks to guide the education and training of both the current and future healthcare workforce. While the Review was asked to focus on the impact of emerging technologies on clinical roles and the consequent implications for education and training, many of the findings will also be relevant to the wider health and social care workforce.[4]

1.5 Overview of the report

This report is structured as follows: the ethical implications arising from the use of digital healthcare technologies are considered in Chapter 2, followed by an overview of the technologies anticipated to impact on the NHS workforce in Chapter 3. This is followed by a granular review of the three over-arching technologies – genomics, digital medicine, and AI and robotics – in Chapters 4, 5 and 6, respectively, and how they will affect patients, healthcare professionals and the health system. The potential healthcare economic benefits are highlighted in Chapter 7. The cross-cutting organisational development needs of the NHS to implement the digital future, including new leadership development, are outlined in Chapter 8. In Chapter 9, the implications for the current and future workforce, and their education and training, are reported. Finally, Chapter 10 summarises the main conclusions of the Review.

2.0 Ethical considerations

There are important legal and ethical implications arising from the use of advanced digital and genomic technologies in healthcare, particularly those concerned with patient safety, data governance, equality and fairness, and respect for human dignity.

2.1 Patient safety

Care must be taken to ensure that digital healthcare technologies are used in ways that remain faithful to the core ethical principle of medical care: 'do no harm'. Recent advances in technological innovations have been so significant in terms of both scale and pace that there has not always been the time and opportunity to fully understand and evaluate their safety and performance. Yet the history of the use of software-driven tools in healthcare, including those approved by regulators, provides sobering and ample evidence of the dangers associated with reliance on new technologies without adequate attention to using them safely.[17] Patient safety training needs to address new risks, including automation bias where clinicians unquestioningly accept machine advice instead of maintaining vigilance or validating that advice.[18] Without robust, resilient, reliable and effective systems for providing trustworthy and evidence-based guarantees of the safety of digital healthcare technologies, there are serious risks that their use might result in harm to patients.

2.2 Data governance

It is vitally important that the underlying data on which many digital healthcare technologies rely are subject to transparent, resilient, robust and legally enforceable data governance structures, policies and practices.[19] Many new and emerging digital healthcare technologies rely critically on the ability to collect, store, access and share medical and other health-related data. The *quality* of the data used to inform these tools, including data gathered through continuous monitoring and tracking that many could consider intrusive, must be assured in order to facilitate their safe and effective use.

For genomic data, the challenges of data governance are particularly complex due to the biological link with relatives, so that an individual's consent to sharing knowledge via genetic testing and donation of their data for specific purposes, such as research, may conflict with the preferences of their relatives who share the same variants.[20]

Without a legally enforceable and effective system of data governance, which the British public regard as ethical, respectful of rights, and secure and trustworthy, the promises of digital healthcare technologies could be undermined. The Universal Declaration of Human Rights states that we all have a right to benefit from science. It is therefore imperative that data sharing should be responsible and ethical so that we can all benefit in meaningful ways from research using these data.[21]

2.3 Respect for human dignity

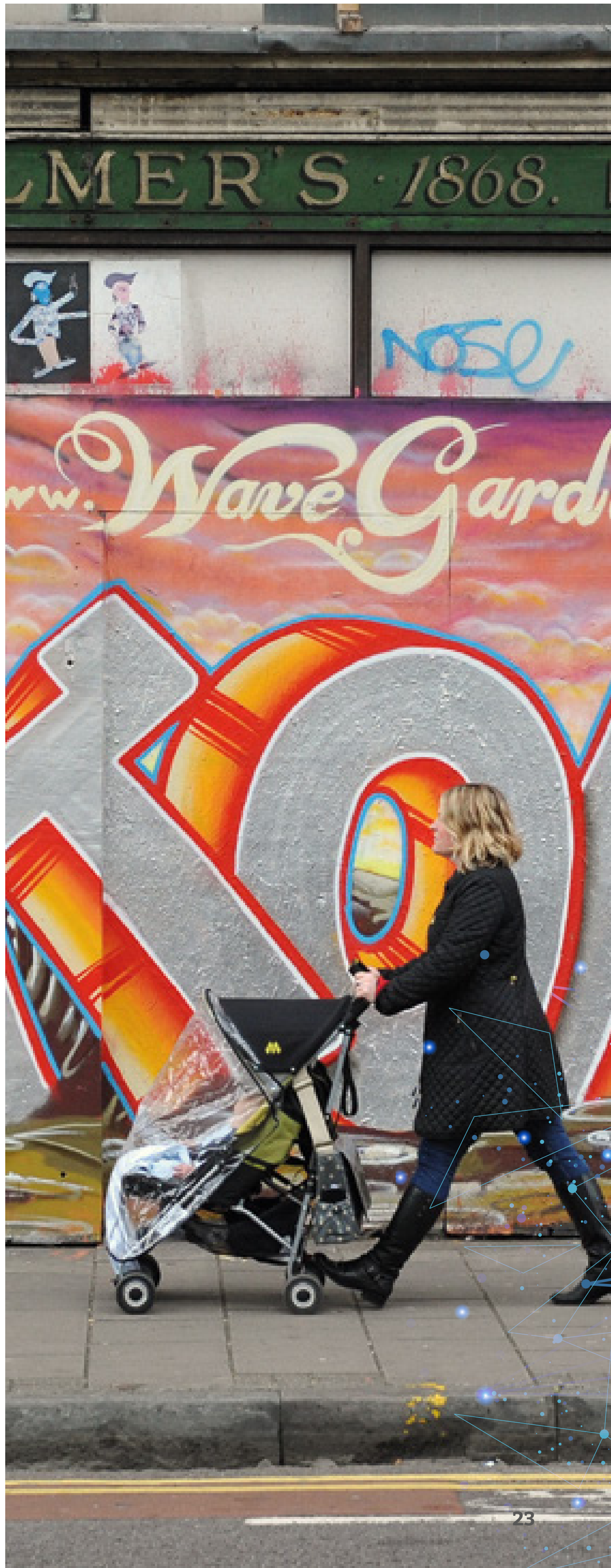
The capacity of AI technologies to mimic human behaviours, including emotional responses, raises concerns that they could be used in care contexts in ways that might be seen as manipulative or deceptive.[22] Users should know whether they are communicating with a person or machine. These concerns reflect a broader anxiety about the risk that advanced technologies may lead to de-humanisation of care. There is also the risk that the automation of key aspects of care to deliver greater efficiency, consistency and reliability might do so at the expense of meaningful human interaction in the care context.[23] Patient and carer involvement in such developments is critical.

2.4 Health inequalities

Health inequalities are differences in health status or in the distribution of health determinants between different population groups.[24] A range of social determinants impact on ill-health and mortality, including quality of education, housing, employment, working conditions and welfare. Differences in these contribute to health inequalities.[25] Technology-enabled healthcare may bring new variants in health determinants.

An individual's engagement with digital technology plays a key role in determining outcomes such as health service uptake, including maintenance of health and wellbeing.[26] The failure to address these issues is creating avoidable cost pressures on healthcare systems in Europe.[27]

Technological innovation in health can help to redress health inequalities, but conversely also has the potential to exacerbate them – driving the first and avoiding the second is a challenge to the system. The NHS is founded on a commitment to the principles of equal and equitable access to healthcare for all UK citizens. Yet the use of digital healthcare technologies could undermine these principles by exacerbating inequalities, unless consideration is given as to how they affect equality and equity, including the risk that vulnerable groups might be excluded or exploited.[28] Care must also be taken to attend to bias in the data used to train the algorithms in clinical AI tools, which inform clinical decision-making. There is the possibility that otherwise high-quality data might reflect the bias inherent in social structures and reinforce existing structural discrimination and inequality.



2.5 Patients and carers

Patients and carers utilise different organisations for the support and help they receive in their lives, from condition-specific support groups to public libraries. Patient education and support is an important part of meeting the new clinical needs brought by technology-enabled healthcare. Where appropriate, the use of patients' own devices will facilitate patient education and may contribute to keeping patients independent for longer.

Carers are already at risk of health inequalities. Many carers are not receiving formal support in their caring role and have very little contact with traditional services for carers.[29] Monitoring technology that provides reassurance or alerts appropriately provides a benefit for both the carer and the person for which they care.[30]

2.6 Healthcare professionals

The workforce will need to assess the level of digital literacy of patients and carers, including the skills to triage a patient or carer, with their consent, by assessing their capacity and willingness to engage, any barriers to their use of technology, such as motility skills, access to computing hardware and connectivity.

2.7 Health system

The successful implementation of technology-enabled care requires the system to deliver targeted support across health and social care sectors and to deploy it to where and when the patient may need it. Monitoring access, usage and outcomes and mapping it to key characteristics, which are markers for inequalities, are essential.

2.8 Widening Digital Participation

The Widening Digital Participation programme is an example of how the NHS has collaborated with a charitable organisation to address the challenges of reducing health inequalities, engaging with groups at risk of poor health, and increasing digital inclusion. The programme focused on increasing the digital skills, knowledge and confidence of those people who experience health inequalities and have been previously excluded from fully participating in their health and care.[31]

The programme used networks, training and innovative approaches to help people improve their digital health skills. It achieved scale and reach, with people learning to access health information online for the first time, feeling more informed about their health and confident about using online tools to manage their health. Additional reported benefits to personal wellbeing included feeling less lonely, feeling happier and gaining improved self-confidence. There was also a recorded behavioural change with people using the internet as their first port of call for information instead of health professionals. There were further identified positive benefits for health professionals, including improvement in their skills and adapting the way that they delivered services.[31]

2.9 Recommendations
The Review Board recommends:

The citizen and the patient

- In a similar way to other public health education initiatives, programmes aimed at engaging and educating the public about genomics and digital healthcare technologies should be developed. (P1)
- The NHS should work with patient and carer organisations to support appropriate patient education. (P2)
- Local arrangements should be established to provide needs-based targeted education and support through existing patient support provision, where possible. (HI1)

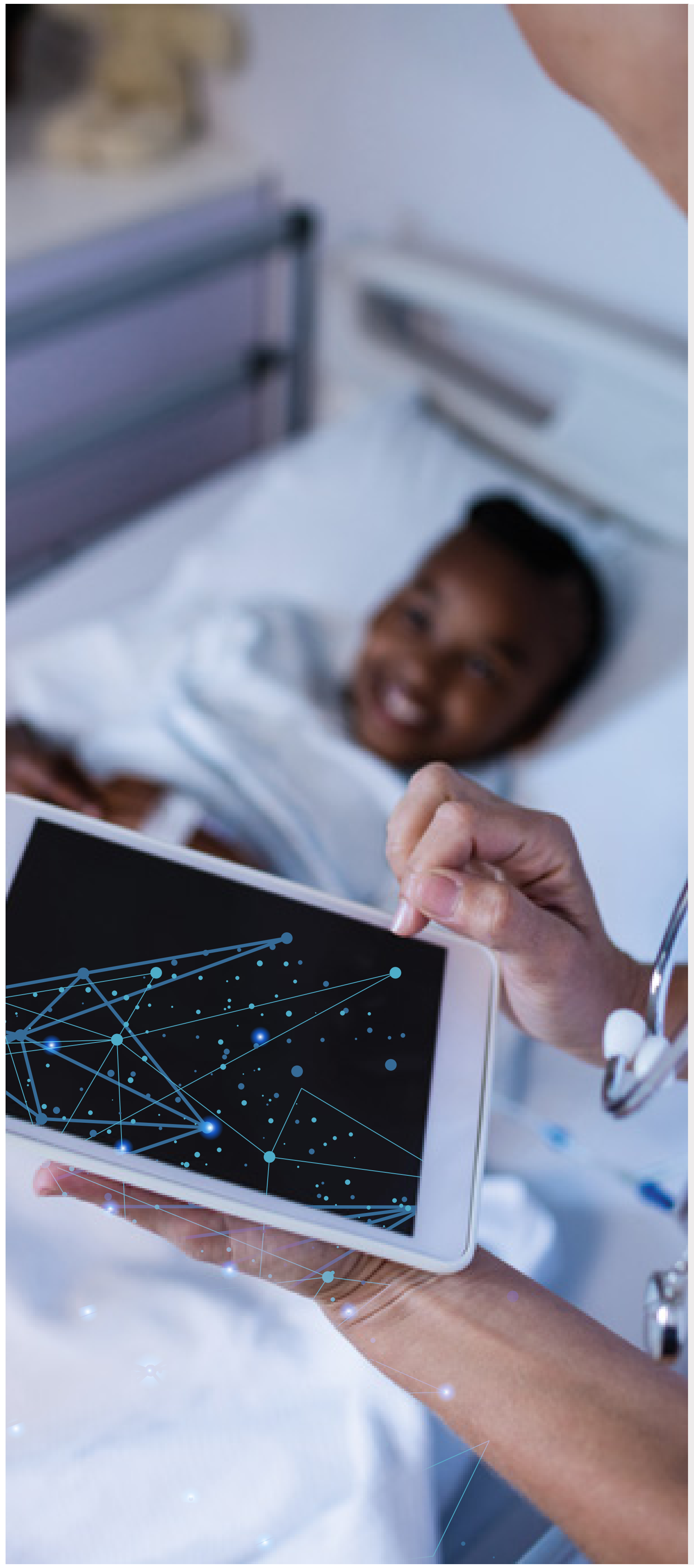
3.0 The top digital healthcare technologies impacting the workforce

In 2016, the Wachter Review concluded that "it would be reasonable to expect all Trusts to have achieved a high level of digital maturity by 2023.[32]"

The current Review strongly supports this ambition. Responding to our call for evidence, senior leaders in arm's-length bodies, regulators and front-line staff advised us that further development of the health IT infrastructure was needed, especially with respect to interoperability across secondary, primary and social care. The Review Board is convinced that implementation of the local health and care record of the future, and of a sustainable infrastructure, are prerequisites for delivering on the potential of the digital healthcare technologies considered in this Review.[33]

Genomics, digital medicine, AI and robotics will change the roles and functions of clinical staff over the next two decades. To illustrate this, the Expert Advisory Panels considered which technologies may have the greatest impact on the healthcare workforce, with the caveat that the development of future technologies is predictably unpredictable. Their findings are summarised below.

Given the unpredictability, **Figure 1** offers a broad outline of the timeline over which the NHS may be expected to adopt each of these technologies at scale. Telemedicine is an example of a technology already in place, but with partial and uneven adoption across the NHS. It is nevertheless likely to be routinely used within a decade. By contrast, genome editing (writing the genome) may have a significant impact on those individuals benefiting from it (and those services delivering it), but it is not yet in place and likely to remain the domain of specialist services for the foreseeable future. The timeline for the heat map represents a judgement based on the complexity of embedding and scaling these technologies, including capital investment and the interoperability required.



Technological advances impacting healthcare and the magnitude of disruption.

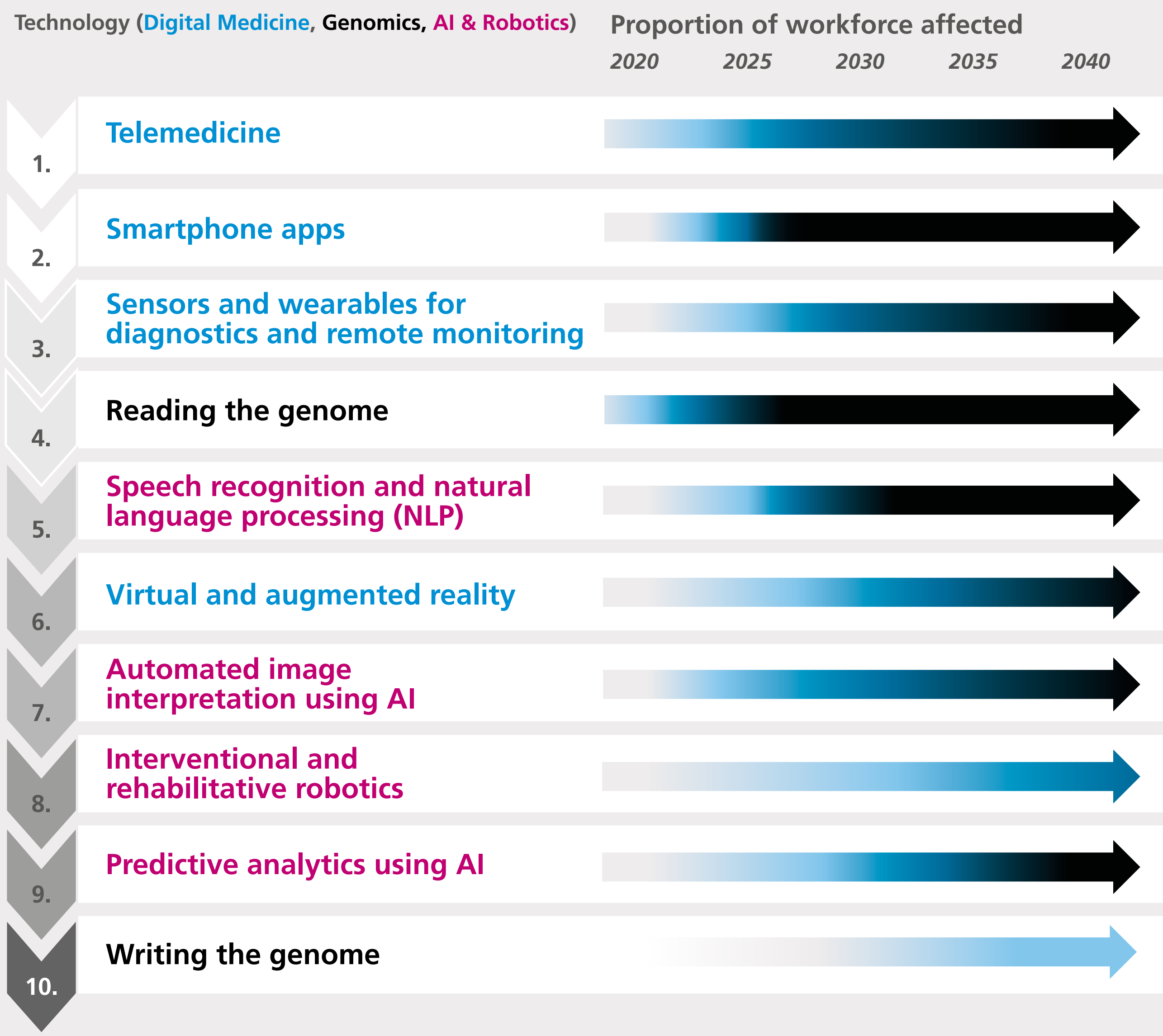


Figure 1: Top 10 digital healthcare technologies and their projected impact on the NHS workforce from 2020 to 2040

Arrow heat map represents the perceived magnitude of impact on current models of care and, by inference, on the proportion of workforce affected

<20% | 20% | 50% | >=80%

3.1 Top technology descriptions

3.1.1 Telemedicine

Telemedicine involves the provision of clinical care from a distance using telecommunication and information technology, including text, audio and video consultation, and is required to deliver the same standard of care as face-to-face consultations.[34] The Royal College of Physicians recently recommended making more use of telephone and video consultations in order to cope with the demand for new appointments, which has doubled in the past decade.[35]

Within primary care, evidence is accumulating that telemedicine benefits some groups, but at this stage of its development and adoption it can be disruptive to the wider health economy.[36] Telephone triage is now well established. Online services, whether directly integrated into the NHS or delivered via commercial providers, are becoming increasingly popular. Potential benefits include ease of access for patients[37] and the reduction of non-attendance rates,[38] although these benefits have to be balanced against increased service cost and demand. Video consultations appear to be well received by patients, with the greatest benefits being seen with specific patient groups as part of their long-term care.[39] Another example of the use of telemedicine is in care homes, where a secure video link between the care home and a healthcare provider enables direct access to medical advice for care home staff and residents.[40]

3.1.2 Smartphone apps

This report is produced at a time when the NHS App is becoming available to all citizens with access to a smartphone.[41] The app allows patients to: check their symptoms using NHS 111 online and/or the symptom checker on the NHS website; book and manage their appointments at their GP practice; order repeat prescriptions; securely view their GP medical record; register as an organ donor; and choose whether the NHS uses their data for research and planning. The NHS App has a secure identification and login process to help keep patient data safe, which has been independently tested against standards set by the National Cyber Security Centre (NCSC).

The NHS has an important role in providing trusted online health information and apps.[42] More than 70 apps are currently hosted on the NHS Apps Library, which is a trusted source of health apps. The level of complexity of these apps varies from simple apps to maintain physical or mental wellbeing to more complex apps to promote self-management, integrated with remote monitoring by the healthcare workforce. The National Institute for Health and Care Excellence (NICE) and NHS England are currently reviewing the level of evidence for clinical effectiveness required for these apps to be approved. Clinical effectiveness is defined as "the application of the best knowledge, derived from research, clinical experience and patient preferences to achieve optimum processes and outcomes of care for patients".[43] A proportionate approach to determining the extent to which apps are safe, offer patient satisfaction and provide more efficient use of clinical services is the goal. This may not always require the use of randomised trial evaluations.

Apps, linked to sensors and wearables (see below), are starting to be prescribed as digital therapeutics for self-monitoring and self-management. In parallel with this, the patient as a consumer of health apps, for example, to monitor heart rhythms with smartwatches, is a growing phenomenon. One of the challenges for the adoption of digital health in the NHS will be how best to integrate these two trends.

3.1.3. Sensors and wearables for diagnostics and remote monitoring

Today an estimated 70-80% of all clinical decisions rely on the result of a test, typically performed in a centralised NHS pathology lab.[44, 45] Advances in sensors and wearables are already beginning to bring diagnostics and monitoring ever closer to the patient, including on hospital wards, out-patient clinics, A&E, GP surgeries, pharmacies and in the home. Examples include:

- **Point-of-care and self-tests:** Advances in sensors harnessing ultra-sensitive bionanotechnologies will transform the rapid diagnosis of disease at the point-of-care, and could result in earlier diagnosis, faster access to treatment, improved antimicrobial stewardship,[46] better health outcomes and disease prevention. New diagnostic technologies will support front-line health workers and also people self-testing at home, where appropriate. HIV self-tests are already available over the counter, offering greater privacy compared to clinic attendance. As testing becomes increasingly decentralised, there is a need for data connectivity to laboratory information systems, electronic patient records, and linkage to care and public health services.[47] A new generation of smartphone-connected diagnostic tests are under development, with the ability to utilise in-built sensors and connectivity to link results to online care pathways.[48]
- **Sensors for self-monitoring:** Self-monitoring and self-management have been the cornerstone of Type 1 diabetes management for three decades, since the first finger-prick blood glucose meters became widely available in the 1980s. The advent of Bluetooth-enabled glucometers linked to smartphones has made self-management easier to integrate into the activities of daily life. In 2018, the US Food and Drug Administration approved the first implantable sensor for continuous glucose monitoring.[49]
- **Wearables for remote vital-sign monitoring:** There is an increasing acceptance of the use of wearable sensors (including the in-built cameras and accelerometers of smartphones) to track vital signs, such as heart rate and abnormal rhythms, respiratory rate, blood oxygen saturation and blood pressure. Elderly patients usually prefer using a computer tablet rather than a smartphone because of the larger screen and keyboard.
- **Video cameras for patient monitoring:** Hospitals and care homes in which frail and elderly patients with cognitive impairment are being cared for usually have video cameras installed in patients' rooms. Computer vision and machine learning algorithms to analyse video data streams can transform the care of these patients, both through early detection of adverse events such as falls[50] and through presenting objective reports of activity and health data to help healthcare professionals proactively plan care. Systems have already demonstrated that nursing staff have more time for hands-on care where they are needed most.[51]
- **Remote monitoring:** The sharing of patient-generated data with the healthcare workforce enables remote monitoring, but this needs to be integrated within clinical pathways. As digital technologies become more prevalent, there is a risk that a deluge of automatically transmitted data will overwhelm healthcare professionals. The application of AI to generate patient summaries may provide a clinically useful solution to this problem.

3.1.4 Reading the genome

The capacity to 'read' an individual's genome and capture the variation within it has been gathering pace for the past two decades. Most clinical applications to date have relied on partial views of the genome (through genome-wide arrays or targeted sequencing), but the UK is pioneering a shift towards implementing full genome sequence for clinical use. The 100,000 Genomes Project, delivered through a landmark partnership between Genomics England and NHS England, has provided a unique insight into the molecular characterisation of rare diseases and cancer.[52] The NHS Genomic Medicine Service will provide a national genomic testing service for all specialties throughout England, with the ambition to perform up to five million genomic analyses over the next five years.[53] This will extend genomic diagnostics beyond rare diseases and cancers, producing benefits in prevention and management of common late-onset diseases that will produce healthcare benefits for all. Genomics will involve all areas of healthcare and impact the patient's entire journey, from diagnosis to monitoring and treatment.

The falling cost of whole genome sequencing means that it will replace other techniques for genome diagnostics over the next 10-20 years. However, in the short to medium-term while it remains relatively expensive, many clinical applications can make use of more limited data. Genotyping arrays that allow stratification of individual levels of genetic risk for a host of common diseases (through 'polygenic risk scores') already cost well below £100, and, at the same time, generate other targeted clinically relevant genetic information (eg pharmacogenetics).[54] Recent research has shown that with limited dedicated training, clinicians are able to convey genetic risk information to their patients and to discuss treatments or lifestyle changes of potential benefit.[55]

The same sequencing techniques allow us to 'read' other genomes of clinical importance, such as those of tumours, the microbiome and pathogenic bacteria, thus extending the scope of genomic medicine.

3.1.5 Speech recognition and natural language processing (NLP)

Smart speakers or voice assistants interpret human speech and respond via synthesised voices. Through automated speech recognition (SR), users may ask their smart speaker questions, control home automation devices, manage entertainment systems and perform administrative tasks by voice command.[56] Popular commercial voice assistants include Apple's Siri, Amazon's Alexa, Microsoft's Cortana and Google Assistant.

Early uptake of SR-based documentation in healthcare has been slow, possibly due to immature technology and clinically unacceptable error rates.[57, 58] With recent advances in SR algorithm design and system performance,[59] this technology now presents a valuable tool for clinical documentation – the benefit for the healthcare workforce to focus on patient interaction and care rather than the computer screen and keyboard is clear. This is likely to have a major impact in primary care, as well as outpatients and emergency departments in hospitals.

An example of an SR application enabled by NLP is a mental health triage bot that analyses text and voice inputs for emotion and suicidal ideation. Its co-design and development with NHS mental health staff ensures that the bot replicates existing clinical practice and meets NICE guidelines. The plan is for this open-source software to be built into the Improving Access to Psychological Therapies (IAPT) pathway, becoming part of the pan-London IAPT triage process.[60]

3.1.6 Virtual and augmented reality

Immersive technologies combine computer-generated visual, auditory and other sensory data with the physical world and present it to the user in such a way as to allow them to interact with the blended environment, typically through a head-mounted display (HMD). This may be in a fully immersed fashion (virtual reality (VR)), overlaid or integrated with the physical world (augmented and mixed reality). Recent developments in computing, optics, and sensors made these technologies widely available, affordable and effective. They are both tools for the delivery of care and a platform through which care delivery can be taught, where they can have a positive impact on learning retention as well as the ability to carry out complex procedures.[61]

The medical applications of VR have been studied since the 1990s, with researchers using the immersive effects of VR to reduce pain and distress for patients receiving wound care.[62] Since then, studies have explored the ability of VR to reduce pain in burns,[63] manage procedural pain,[64] and distract from acute pain.[65] In mental health, VR has also been used with benefits in post-traumatic stress disorders,[66] anxiety[67] and phobic disorders.[68]

3.1.7 Automated image interpretation using AI

Deep learning provides enhanced diagnostics through automated image interpretation, for example, in dermatology, radiology, ophthalmology and pathology. Digitised medical scans are becoming readily available to train deep learning systems.[69] These trained systems will then reduce the cost and time involved in analysing scans.[70]

Deep learning technologies have already shown expert-level performance in medical image analysis, for CT scans, mammograms, retinal scans and pathology slides. They also show promise in reducing acquisition times for MRI scans, and decreasing CT and PET radiation doses. Analysis of images recorded with a smartphone camera may allow patients to monitor the progress of skin lesions, aiding early diagnosis of serious lesions and providing them with a measure of reassurance when lesions are benign.[71]

3.1.8 Interventional and rehabilitative robotics

Robots in healthcare have been designed to address specific procedural technical challenges, for example, surgical robotics. There is some evidence to support robotic assistance in the performance of abdominal and orthopaedic surgery.[72, 73] Snake robots for reaching peripheral areas in the lungs or for performing gastrointestinal surgeries have recently become available, expanding the scope of robotics in surgery.[74, 75] Robots can also automate high-volume repetitive tasks, for example, dispensing in pharmacy.

Rehabilitative and wearable robots, including prostheses, exoskeletons and brain-machine interfaces will allow advanced functionality to some patients with physical disability. Examples of leading-edge robotic technology include the manufacturing and fitting of an advanced bionic arm based on 3D scanning and printing.[76] Finally, robots can also provide patient support, for example, pillbots and companion robots.

These technologies have clear implications for the education and training of the workforce. Specific training on new robotic platforms will be needed for surgeons and theatre staff. Planning and fitting processes will be needed for prosthetists and orthotists, while physiotherapists and occupational therapists will need to develop new skills in supporting the patient to achieve the maximum functional benefit from their prosthesis.

3.1.9 Predictive analytics using AI

Predictive analytics and modelling are not new to healthcare. Clinical risk scores based on statistical regression models have been used for decades. The use of predictive modelling in assessing frailty of old age is an important example of the need for risk prediction. In 2017, the NHS began to deploy predictive analytics at population level to assist with the proactive identification and subsequent assessment of older people living with frailty. The Electronic Frailty Index uses health data routinely collected in GP record systems, which is available to all general practices, and allows local identification of older people at risk of adverse health outcomes and care home admission.[77]

Predictive modelling using machine learning applied to large, carefully annotated datasets is a more recent advance, for example, personalised treatment algorithms, patient triage algorithms and risk prediction.[78, 79, 80, 81] Deep learning methods applied to electronic patient record data have been shown to be capable of accurately predicting multiple medical events from multiple centres.[82] AI can also identify unexpected physiological deterioration and predict subsequent outcomes for in-hospital patients[83, 84, 85] and help to predict individual response to treatment.[86]

3.1.10 Writing the genome

The advent of powerful genome-editing and synthetic biology tools holds the promise of benefiting patients through the ability to 'write' as well as read genomic information. CRISPR/Cas9 is a revolutionary specific gene-editing system that allows specific corrections in an individual's DNA to be made. Responsibly used, this brings the potential for cures for previously untreatable rare diseases, and opportunities to develop entirely new, targeted therapeutic strategies.

Clinical trials are under way across the world exploring the use of gene editing in rare diseases such as haemophilia and cystic fibrosis, and in 2017 the NHS approved the use of gene therapy for a rare form of severe combined immunodeficiency – ADA-SCID.[87, 88] While the technology has the potential to evolve, it is likely to continue to be implemented in highly specialised centres, with UK specialists proceeding in step with their international colleagues to build best practice from technical, clinical and ethical perspectives.

Advances in gene-editing technologies have the potential to accelerate genomic engineering strategies. These may deliver a wider range of personalised treatments such as Chimeric Antigen Receptor (CAR) T cell therapy, which uses a patient's own immune cells (T cell) to target specific receptors on cancer cells.[89] This therapy has recently been approved for use in specific B-cell lymphomas and Non-Hodgkin Lymphoma in the UK, with development focusing on the potential impact on solid organ tumours in the future.[90]

3.2 Use cases

Maximising the potential of these technologies could deliver significant improvements in patient care, improved productivity of healthcare staff and reduced costs.

1. Telemedicine – Virtual fracture clinics:

Need

There is a large and increasing demand on traditional and outdated fracture clinics services. New patients are not seeing the right consultant for their injury. Additionally, there is significant variation in management plans and suspected over-imaging with unnecessary follow-up when seen by junior staff.

Solution

Service redesign at Brighton and Sussex University Hospital Trust, introducing a virtual fracture clinic for acute fracture and soft tissue injuries in a patient-centred, standardised, safe and effective way. This includes a telephone consultation (combining an orthopaedic review and specialist therapist input) and self-management through use of online resources, with subsequent appointments only where clinically indicated.

Outcome

- The virtual fracture clinic model is able to monitor and meet adherence to fracture clinic guidelines. It has been shown to be safe with no related serious complications.[91,92]
- In 2017, over 50% of the 8,000+ new patient fracture clinic appointments were via the virtual fracture clinic and discharged after receiving virtual care. This represents a saving for the Clinical Commissioning Group (CCG) of over £700,000.[93]

Roles/functions change

- Virtual services provide faster access to specialist orthopaedic review.
- Consultants review patients within 72 hours of referral and no longer see every patient face to face.
- New patient fracture clinics are now specialist clinics, with the patient seeing the right consultant for their injury.
- New roles for advanced clinical practitioners and senior therapists have been created.

Education/training requirements

In-house training is provided to upskill therapists in specialist areas, such as imaging, acute injury management and digital technologies.

2. Smartphone apps – Computerised cognitive behavioural therapy (CBT):

Need

Insomnia is a significant public health problem that is highly comorbid with both physical and mental health conditions. First-line recommended treatment is CBT for insomnia, lasting longer than four weeks. However, the ability to provide CBT to a large population is not possible using traditional methods.

Solution

Computerised CBT for insomnia treatment, as a fully automated, advanced algorithm-driven program or app being used without any support from a human therapist, offers a solution to the problem of scalability. CBT is particularly appropriate for digitisation, given its structured format, emphasis on active participation, and self-monitoring and intra-session 'homework' requirements.

Outcome

Computerised CBT for insomnia has been shown to be an effective treatment with effects comparable to those found for face-to-face therapy.[94]

Roles/functions change

- The clinical workforce (mainly primary care) will need to develop their role as digital prescribers.
- They will also need to act as data interpreters to understand the results of the patient's use of the app.

Education/training requirements

- Critical judgement skills in evaluating resources (risks, benefits and indications for).
- Data analysis skills.
- Improved understanding of the regulation of digital therapeutics.

3. Web app – Online chlamydia pathway (OCP):

Need

Chlamydia, the most common STI in the UK, can be easily treated with antibiotics, yet has potential serious sequelae if not treated early. Given it is largely asymptomatic, active case finding is a priority, yet there have been sustained cuts in sexual health services spending despite a rising demand.

Solution

The OCP, within an eSexual Health Clinic, is an automated online clinical consultation model with electronic prescribing, partner notification, health promotion and surveillance. This enables self-directed (including self-swabbing) online care integrated within a specialist sexual health service.[47]

Outcome

- The eSexual Health Clinic has been shown to be safe, feasible and acceptable, with the OCP meeting national standards and regulatory requirements.
- Preliminary evidence of clinical outcomes is comparable to current care for individuals with chlamydia

Roles/functions change

- Staff need to acquire skills in telephone consultations and management to support people online and route them into care if appropriate, and in monitoring patients remotely via an online interface.
- Clinical staff need to address the likely change in case mix of patients attending clinic, as a greater proportion are likely to be more clinically complex.

Education/training requirements

Understanding of:

- how new technologies can fit into the NHS and how to redesign existing care pathways around new technology;
- the potential for digital health, including the pros and cons, particularly the potential for widening health inequalities;
- concepts of health literacy, digital literacy and eHealth literacy;
- the science of developing online consultations;
- evaluation of complex interventions.

4. Automatic image interpretation – Breast cancer screening:

Need

Breast screening using mammography has saved many lives. In the UK the standard is double reading of mammograms by two experts, which improves accuracy. However, there is a workforce crisis with too few experts available to meet demand.

Solution

A UK software company is helping radiologists detect breast cancer using deep learning. The technology aims to ease the workload of overstretched screening units by serving as an independent reader to support breast screening programmes. It also potentially increases the accuracy of screening by reducing the number of false positives and false negatives, saving valuable NHS resource.

Outcome

- The software has received CE marking (Class IIa) and is undergoing clinical trials in an NHS Test Bed and across Europe.

Roles/functions change

- Acting as a blinded reader in a double-reading setting, the technology increases turn-around time for double-reading and potentially reduces the number of unnecessary biopsies and missed cancers, freeing up radiologists to focus on more complex imaging modalities.

Education/training requirements

- Radiologists and trainees will be able to enhance their own diagnostic skills through learning from the technology.
- They will require critical appraisal skills to work out which patients the technology should and should not be used for, and to gauge the accuracy of the software.
- They will also need to be aware of how to promptly report any concerns they have over the technology.

5. Speech recognition and natural language processing (NLP) – Mental health triage bot:

Need

Patients with acute clinical concerns over their mental health often struggle to access services and get rapid access to triage and treatment.

Solution

Chatbot technologies that use NLP will allow individuals to log and monitor health information. An NLP-enabled mental health triage bot has been created, which analyses text and voice inputs for emotion and suicidal ideation. The open-source software is to be built into the GP practice Improving Access to Psychological Therapies (IAPT) pathway.[95]

Outcome

- AI-powered bot benefits the patient through its constant availability and through negating the need for travel for a triaging consultation.
- For clinicians it is estimated that the bot saves approximately one hour of their time per service user.

Roles/functions change

- Less time-consuming initial triage needed by frontline primary care and community mental health teams.
- Cases identified quickly and safely with appropriate streaming of referrals.

Education/training requirements

- Data derived from the chatbot can be used to train clinicians and to improve both the technology and service design.
- Critical appraisal skills needed to work out which patients the technology should and should not be used for, and to gauge the accuracy of the software.
- Clinicians need to be aware of how to promptly report any concerns they have over the technology.

3.3 Future scenarios

6.

Liquid biopsy:

Future technology

Liquid biopsy can identify circulating tumour DNA (ctDNA) in the blood or other bodily fluids to detect and monitor cancer.[96] With sensors expected to improve in accuracy in the next decade, more widespread use of liquid biopsies to detect and monitor cancer is likely.[97, 98]

Liquid biopsy will have transformative potential for patient outcomes, as early detection could reduce cancer mortality and reduce the need for aggressive treatment, which is often required for advanced stage cancers.

Potential use in NHS

With wider research evidence, population-based screening for ctDNA or other molecular cancer markers may become feasible. Improved cancer survival may result as cancer may be detected prior to spreading to other parts of the body.

The technology may be particularly useful for solid organ cancers such as ovarian cancer that typically evade detection by conventional screening methods, which can be more invasive.[99]

Roles/functions change

- Increased liaison with community services.
- Fewer radiological scans and less aggressive treatments as cancer is detected earlier.
- Centralised genomic services to analyse and interpret tumour genomic data to compile personalised genetic profiling of tumours.

Education/training requirements

- All cancers are driven by genetic changes, so understanding the principles of genomics are important for healthcare professionals in the community.
- Understanding the technology as a mechanism to detect cancer, and effectively explaining testing to patients.
- Bioinformaticians and clinical data specialists are integrated into clinical oncology services.

7.

Polygenic risk scores:

Future technology

Genomic factors play an important but complex role in the development of many long-term chronic diseases.

By sequencing markers across the genome, specific genetic variants associated with disease can be detected.

Polygenic risk scores, used in conjunction with existing demographic and lifestyle scoring may be used to predict future risk of diseases such as coronary heart disease (CHD) in the general population.[100] A particular feature of genomic risk scores is that they can be applied much earlier when any preventative measures may be most effective.

Solution

Earlier identification of members of the population who are at an increased risk of complex diseases who can then be targeted for more support in lifestyle changes or placed on preventative medication. An example would be earlier and more cost-effective use of statins to reduce development of CHD for those at higher genomic risk.[101]

Roles/functions change

- Blood tests could be undertaken as part of routine health-checks, in the community, to analyse an individual's genetic risk for complex diseases such as CHD.
- Test results provided in an accessible manner to GPs, nurse practitioners or hospital specialists to discuss with patients, at an appropriate time, as part of their routine care in a manner analogous to their discussion of other risk factors – an example of 'mainstreaming' of genomics.

Education/training requirements

- Understanding genomic testing, and interpreting polygenic risk scores.

8.

Interventional robotics:

Future technology

The continuing miniaturisation and sophistication of electronics that can be incorporated in a range of robots is likely to revolutionise how and where invasive procedures are performed. Currently, most robots in healthcare operate with relatively low-level embedded AI. However, as robots get smaller and smarter, procedures will become less invasive and less painful, need less specialised equipment, and reduce the requirement for lengthy and expensive operator training.

Solution

In the UK, colorectal cancer is the second most common cancer by incidence and third in mortality. Colonoscopy procedures are fundamental to the management of colorectal cancer.

Robotic colonoscopy, under development at the University of Leeds and next to first-in-human trials, is designed to be painless and extremely easy to perform. The platform is based on an enhanced magnet-driven robotic arm, a camera and cutting tool attached to a thin tether linked to computers. AI aids the operator in recognising colorectal cancer and planning the therapeutic approach.[102]

Roles/functions change

- AI augmentation will allow the procedure to be performed by staff (eg primary care clinicians) who do not require the lengthy training or accreditation required for flexible endoscopy procedures.
- Procedure can be performed by clinicians in the community, without the need for anaesthetic cover or support.

Education/training requirements

- Training in working with the robot and in the clinical appraisal of AI-based automated image interpretation and diagnostics.
- Training to use the robot should be a short, focused course, preferably performed at a simulation centre.
- Certification/accreditation is required with methods for annual re-certification.

9.

Predictive analytics:

Future technology

Risk assessment and prognosis are crucial in many areas of medical practice. Predictive analytics, based on machine learning, have recently been shown to provide more accurate predictions than clinical risk scores. An important recent advance is the AutoPrognosis[103] framework, for risk score development in varied clinical settings. It can automatically discover the relevant risk factors and automatically makes design choices on which algorithms to use. This framework will provide medical clinicians and researchers, with little or no expertise in machine learning, the ability to develop the risk scores needed for their particular situations,

Solution

Predictive analytic[104] based on AutoPrognosis have shown a 35% improvement in prediction accuracy, compared to existing statistical methods or clinical risk scores, for determining whether a cystic fibrosis (CF) patient should be referred for a lung transplant.

The same AutoPrognosis framework was shown to estimate cardiovascular risk more accurately than current risk scores, especially for patients with co-morbidities such as diabetes.

Roles/functions change

- As predictive analytics are increasingly used and embedded in the electronic patient record, their use will become more ubiquitous. They can be used by clinicians and nurses to better diagnose the patient at hand and by healthcare policy makers to enhance and individualise screening programmes, leading to better allocation of clinical resources.

Education/training requirements

- Learn how to integrate predictive analytics into the care and diagnosis pathway, and interpret predictive results.
- Educate/train clinicians and scientists to use frameworks like AutoPrognosis in order to design new predictive analytics, which may be useful for a specific clinician or healthcare organisation.

3.4 The next 20 years

Within the next two decades, the NHS workforce will access genomic, anatomical and physiological information, as well as social, behavioural and environmental data. The fusion of genomics, digital medicine, AI and robotics will enable staff working within an ethical and legal framework to deliver a more holistic approach to personalised healthcare and disease prevention. With wider use of genome sequencing, we are likely to be able to predict which antibiotics are suitable for particular infections. Prescribing decisions will be made according to the patient's or pathogen's genetic sequence, rather than being based on population-level guidelines. By combining genotypic information with accurate phenotypic data (extracted from wearable sensors, the electronic patient record, or both), we will be able to prescribe the optimal anti-hypertensive drug to treat that individual patient's high blood pressure.

The convergence and complementarity of the three major technologies – genomics, sensors and AI – will enable the development of virtual medical coaches (see **Figure 2**).[105] Integration of these multi-modal data has the potential to achieve prevention for patients at high risk of a particular illness, or at the very least help a person self-manage a chronic condition. Similarly, the integration and analysis of data from multiple sources, including vital-sign data, will underpin real-time remote monitoring of patients to pre-empt hospitalisation. The full potential of health monitoring will be realised when individualised models underpin the monitoring algorithms.[106] Rather than relying on a concept of the normal derived from population studies, AI techniques such as deep learning will be used to define normality for an individual, and hence identify any deviation from it, using that individual's genomic, anatomical, phenotypic and environmental data, and its variations over time.

Each of the technologies reviewed in this chapter will serve a purpose, but the development of synergistic technologies that create, capture, interpret and integrate data will provide the fullest picture of an individual's or population's health. This is the ultimate goal of the next two decades, and the NHS *"as the single biggest integrated healthcare system in the world is uniquely poised to achieve this"*.[107]

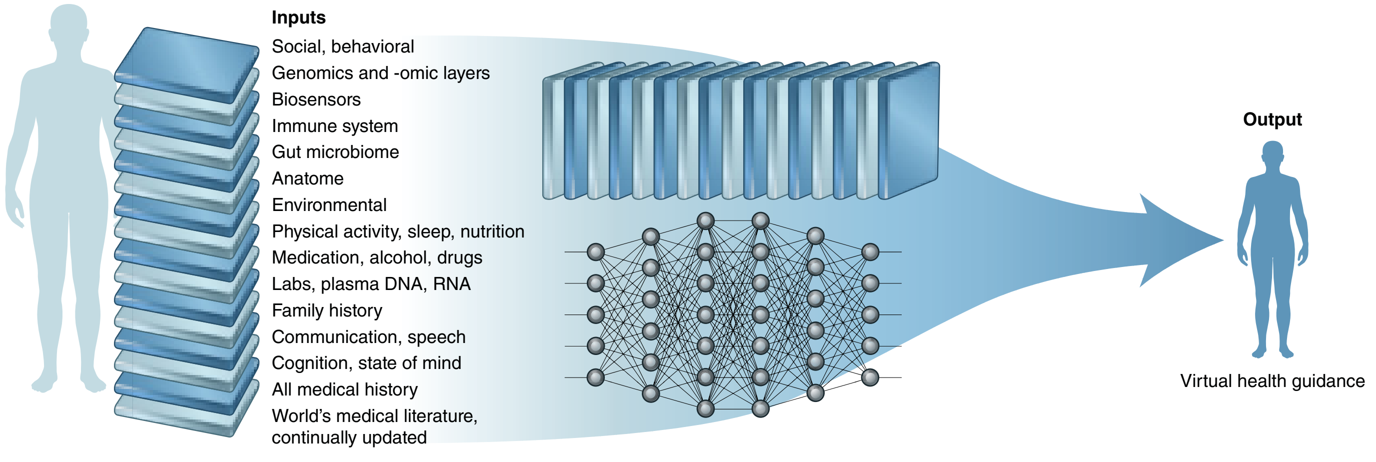


Figure 2: The virtual medical coach model with multi-modal data inputs and algorithms to provide individualised guidance.[105]

> In the foreseeable future, information from an individual's DNA sequence will become part of their medical record and used to inform their healthcare in many different ways throughout their life course."
>
> **Sir Nilesh Samani**

4.0 Genomics

Genomics has the potential to transform healthcare in the NHS as well as dramatically improve patient outcomes in the UK. The world-leading 100,000 Genomes Project, delivered through a partnership between Genomics England and NHS England, was the first step towards the routine application of whole genome sequencing within the NHS.[52, 108]

The newly created NHS Genomic Medicine Service will provide a national genomic testing service for all specialties and equitable patient access throughout England.

The costs of 'reading' the genome – through whole genome sequencing and/or other more targeted strategies – are projected to decline, enabling accelerated roll-out of these approaches across the NHS. Over the next five years, the ambition is for the NHS to perform up to five million genomic analyses, extending genetic diagnostics across diverse specialities, and improving health outcomes well beyond the initial focus on rare diseases and cancers.[53] Preventative strategies for many common, late-onset diseases will be enhanced through improved quantification of genetic predisposition based on polygenic risk scores. Genetic diagnostics will enable more efficient targeting of drugs, maximising efficiency, optimising dose and minimising side effects. Increasingly, primary bioinformatic analysis and clinical interpretation of genomic findings will be delivered through high-throughput automated approaches.

Other types of genomic tests will extend our ability to capture dynamic events relevant to health, including applications in foetal diagnostics, the early detection, surveillance and molecular characterisation of cancers, the influence of the gut microbiome, and – through analysis of RNA, protein and metabolomics biomarkers – the evolution of inflammatory and metabolic disease. Likewise, the ability to read the genomes of pathogens such as bacteria and viruses will continue to transform microbiology, supporting more rapid and accurate diagnostics, optimisation of therapy, surveillance of infectious disease outbreaks, and more effective strategies for tackling antimicrobial resistance.[109]

The advent of powerful genome-editing and synthetic biology tools will benefit patients through the ability to 'write' as well as read genomic information. It is now possible to make specific corrections within an individual's DNA that could render cures for previously untreatable rare diseases and deliver targeted therapies.

Until now the focus has been on the use of sequence data to support the diagnosis of rare diseases and to characterise cancers, but the future will bring a broader application of genomics to improve outcomes for patients across the NHS. The NHS workforce will play an essential role in ensuring that genomic technologies are efficiently, appropriately and equitably deployed.

4.1 The citizen and the patient

We anticipate that in the foreseeable future and subject to their consent, each individual will have information derived from their genome sequence available in their medical record. This will support diverse healthcare applications of genomics throughout an individual's life, including the evaluation of disease predisposition, more accurate diagnoses and personalised optimisation of therapeutic and preventative interventions. Citizens need to be empowered to understand how genomics may affect their health, to make informed decisions about their care, and to recognise the personal and family-wide implications of the findings that genomics may bring. Initiatives such as Genomics England's 'Genomics Conversation' are expanding our understanding of societal attitudes, aspirations and concerns.

Genomic data can raise complex issues around risk, ethics, privacy, insurance, employment and fertility. Robust and sustained ethical oversight of genomic data handling will be needed to maintain public trust and support. We recommend that the NHS, in partnership with relevant regulatory bodies, should establish a clear, robust framework through which healthcare professionals use genomic data, which safeguards patient confidentiality and inspires the support and confidence of citizens and the wider community (G1). Patients and the public need to be reassured about the impact of predictive genomic testing on medical insurance and employment. We support the Code on Genetic Testing and Insurance, an agreement between the Government and the Association of British Insurers (ABI) on how insurers use genomic information.[110] The ethical framework for genomics should benefit from collaboration with patient groups and practical support to ensure a full discussion about the benefits and risks of genomic testing and genomic therapy, and to provide clear guidance to healthcare professionals.

4.2 Healthcare professionals

The roll out of genomics across the NHS will have major implications for the clinical workforce. The pace of change may differ by speciality but, ultimately, genomics will impact on the practice of most, if not all, health professionals. While some aspects of care, such as the management of rare genetic diseases will remain largely within the domain of specialised colleagues, many aspects of genomics, including risk prediction for common diseases and pharmacogenetics, will become 'mainstream' and their application embedded in routine healthcare delivery. As practice in genomics evolves, individual workforce training needs will depend less on traditional role demarcations and more on specific responsibilities related to 'real-world' implementation based on genomic information.

With genomic testing set to become integral to all medical specialities, we recommend that all healthcare professionals should receive core training in genomic literacy to help them understand the basis, benefits and ethical considerations associated with genomics (G2). This will ensure that all healthcare professionals (including those without clinical training, such as care commissioners) are aware of the broad principles of genomics, including the contribution of genetic variation to rare and common diseases, use of genomic testing to improve clinical outcomes, genomic counselling, ethics, data security and governance. Healthcare professionals should be confident discussing genomic testing with patients (including options for research participation), requesting appropriate genomic tests, interpreting reports, communicating impact and risk, and implementing evidence-based changes in clinical management. Training in interpretation and communication of genomic findings should be available as accessible online modules, with signposting to further learning, for example, through Health Education England's Genomics Education Programme. Training should be acknowledged by relevant professional bodies responsible for continuing professional development, in line with the Chief Medical Officer's recommendation.[111]

Furthermore, we recommend that lifelong training should be available to healthcare professionals with an emphasis on continuing support in this rapidly evolving field, including access to dynamic 'just-in-time' digital updates and online genomic information resources (G3). Access to online 'just-in-time' educational training and support will ensure that healthcare professionals are empowered to apply the latest advances and recommendations in their decisions about testing, as well as to support the interpretation and communication of results to patients and their relatives.

In many medical specialities, more intensive training will be required to ensure that healthcare professionals – those in training and those who are already in post – are equipped to access and interpret complex genomic analyses. Obvious examples include oncology, clinical microbiology and paediatrics, though we anticipate much broader requirements as science and medical practices evolve. We recommend that accredited genomic training for healthcare professionals should be established in key clinical specialities to incorporate genomic testing and genomic counselling into their practice (G4). We envisage these advanced modules being delivered through a combination of online courses and peer-delivered contact teaching, incorporating contextualised learner-driven scenarios. This training must be recognised and accredited by the Royal Colleges, the National School of Healthcare Science and other relevant agencies. Healthcare professionals will need to be given the time to train, to develop new skills (particularly in the communication of genomic results), and to incorporate evidence-based guidance into their clinical practice. Trainers should also demonstrate their aptitude for high-quality delivery of learning through formal training and institutional support.

The successful implementation of genomic medicine within the NHS will also require investment in a variety of specialist healthcare roles. We recommend that capacity be built within the NHS Genomic Medicine Service through support for specialist healthcare professionals, including genomic counsellors, clinical scientists and specialists in genomic medicine (G5). For example, clinical scientists will be needed to support the development and delivery of population-based standardised molecular testing, informatics and clinical interpretation pipelines, interacting with other healthcare professionals to ensure that appropriate evidence-based care pathways are implemented. Genetic counselling and clinical genetic services will require sufficient capacity to fulfil both their existing specialist roles and to diffuse their expertise across the NHS. Counsellors and specialist physicians will have an extended role in training, provision of referral services (for example, via virtual multi-disciplinary team meetings), support for mainstreaming, and contributions to genomic leadership. They will have a leading role in the development of complex, ethical, patient-led management that encompasses an understanding of how genomic data can lead to a long-term duty of care that extends beyond the index cases to their wider families, and a need to convey complex risk and other probabilistic information.

4.3 Health system

Substantial progress in service transformation to deliver genomic medicine has already occurred throughout the NHS. The inauguration of the NHS Genomic Medicine Service will allow all healthcare professionals across England to deliver the benefits of genomics to patients.

To support appropriate interpretation and communication of results, relevant guidance for each genomic result should be accessible directly from the standardised reports generated (increasingly through automated processes) by the NHS Genomic Medicine Service, along with signposting to additional 'just-in-time' educational resources. Facilitated access to specialist genomic support services, enabled by digital technology, should empower healthcare professionals to embrace genomics in their practice. This will be accompanied by an acceleration of the shift towards multi-disciplinary working, and 'one-stop' patient evaluation and management.

Delivery of the benefits of genomics is critically dependent on expert computational analysis of biological data across the health service. The NHS needs to attract, recruit and retain talented science, mathematics and computing graduates to fulfil leadership roles in computational genomics, data science and public health informatics (collectively, 'bioinformatics'). We recommend development and implementation of an attractive career pathway for bioinformaticians, including expansion of Higher Specialist Scientist Training for clinical bioinformaticians (G6). Individuals with these skills will be increasingly embedded across medical specialities in the NHS, through the appointment of consultant-level bioinformaticians who can lead research, education and practice within multi-professional clinical teams. It will also be vital to support methodological and mechanistic research in the academic sector, which uses consented and de-identified NHS data to advance translational objectives.

Clinical leadership builds excellence within multi-disciplinary teams and improves patient outcomes. We recommend development of a framework for genomic leadership across clinical specialities and primary care settings to encourage and disseminate best practice and to simplify patient referral systems (G7). These genomic leaders, based within medical or scientific specialities and primary care environments, will provide the link between centralised genomic services, the wider healthcare profession and the patient community, and will form facilitative networks to share information and to promote and disseminate collective expertise. These networks will need to act at both the national level (for example, to coordinate management of particular rare diseases) and locally (for example, to provide support and expertise across a group of primary care practices). Genomic leaders will have an important role in shaping the informational content of genomic reports, providing a platform for rapid referral in non-standard cases (through online consultation), remotely attending genomic multidisciplinary team meetings, providing advice on communication and ethical questions, and/or consulting on genetic variants relevant to their specialist clinical area. We envisage that genomic leaders will arise from a variety of professional roles, including physicians in clinical specialities, genomic counsellors, clinical scientists and primary care practitioners.

To ensure that the future workforce is in a position to contribute to the implementation of genomics, we recommend that academic institutions should ensure genomics and data informatics are prominent in undergraduate curricula for healthcare professionals, and that there should be expansion of undergraduate capacity in genomics, bioinformatics and data science (G8). This undergraduate training should focus on core principles and skills, such as the capacity to evaluate genomic data and to understand and communicate complex issues of probability and risk, which will be part of most, if not all, clinical specialities. Emphasis should be placed around cross-cutting genomics themes (for example, pharmacogenomics) of direct clinical relevance to all graduate prescribers. Investment in undergraduate education needs to extend beyond clinical training to ensure the future supply of non-clinical scientists with relevant skills, and to equip both groups with a common vocabulary and intellectual framework that will encourage productive interaction. This will ensure that we have an agile workforce, equipped with skills to appraise and facilitate future innovation in the NHS.

The NHS needs to ensure that the efficiencies in healthcare delivery that result from the introduction of genomic medicine lead to manifest and tangible benefits in the quality and outcomes of care delivered to patients and the wider community. This will involve a more equitable relationship between the patient and their clinician, recognising that wider access to information and personal empowerment will result in citizens being more informed about their health, and who expect shared decision-making.

> "The expansion of genomics into medical care will be incremental, but over the next two decades, their combined effects will transform the practice of medicine, with substantial consequences for the NHS workforce."
> **Professor Mark McCarthy**

4.4 Recommendations
The Genomics Panel recommends:

The citizen and the patient

- The NHS, in partnership with relevant regulatory bodies, should establish a clear, robust framework by which healthcare professionals use genomic data, which safeguards patient confidentiality, and inspires the support and confidence of citizens and the wider community. (G1)

Healthcare professionals

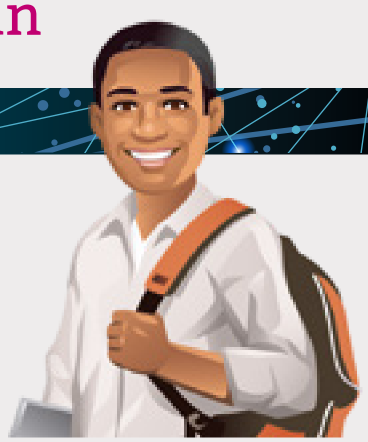
- All healthcare professionals should receive core training in genomic literacy to help them understand the basis, benefits and ethical considerations associated with genomics. (G2)
- Lifelong training should be available to healthcare professionals with emphasis on continuing support in this rapidly evolving field, including access to dynamic 'just-in-time' digital updates and online genomic information resources. (G3)
- Accredited genomic training for healthcare professionals should be established in key clinical specialities to incorporate genomic testing and genomic counselling into their practice. (G4)
- Capacity should be built within the NHS Genomic Medicine Service through support for specialist healthcare professionals including genomic counsellors, clinical scientists and specialists in genomic medicine. (G5)

Health system

- An attractive career pathway should be developed for bioinformaticians, including expansion of Higher Specialist Scientist Training for clinical bioinformaticians. (G6)
- A framework for genomic leadership should be developed across clinical specialities and primary care settings to encourage and disseminate best-practice and to simplify patient referral systems. (G7)
- Academic institutions should ensure genomics and data analytics are prominent in undergraduate curricula for healthcare professionals, and that there should be expansion of undergraduate capacity in genomics, bioinformatics and data science. (G8)

Persona: Eddie the bioinformatician

Eddie in 2013, aged 21:



Eddie is a final-year zoology undergraduate. His dissertation involves studying the phylogenetics of old-world parasites and he has recently learned how to analyse genetic sequences of insects. His housemates are studying medicine and physiotherapy. He feels that working within a team environment in the NHS would suit him. He is interested in genomics and decides to pursue training as a bioinformatician. Eddie is delighted to be accepted for the post-graduate NHS clinical scientist training programme in clinical bioinformatics.

Eddie in 2019, aged 27:

Eddie is now a clinical scientist working as a bioinformatician in a Genomic Laboratory Hub within a large NHS University Hospital Trust. His training programme helped develop a wide array of skills that have enabled him to respond flexibly to the rapidly changing needs of the service. His communication and research skills are major assets for his job.

Eddie is excited by the potential of emerging technologies that allow the detection of molecular disease markers in patients and are affordable enough to be used routinely in clinical practice. He uses his skills in computational genomics and statistical biology to work with colleagues in developing improved bioinformatics tools for identifying complex genetic variants.

He also spends part of his time on the genetic analysis of the data generated from the 100,000 Genomes Project. He is enjoying the opportunity of working at the leading edge of genomics knowledge and finding new genetic diagnoses in patients with rare haematological diseases.

Eddie in 2029, aged 37:

Eddie is now a consultant bioinformatician specialising in haematological cancers. He is an integral member of the team providing a specialist haematology clinical service. His clinical responsibilities include analysing genomic data from live tumour cells for new variants that may require a change in medication or more targeted treatment.

He is a lead member of a research group developing new personalised treatments for rare haematological cancers. His work in evolving new technologies involves collaborating with clinicians, other healthcare scientists and computer scientists to develop tools to improve diagnostic accuracy and yield through better integration of disparate data types.

Eddie also spends time teaching patient groups and primary care physicians in the community, and curating new educational resources for patients, clinicians and healthcare scientists. He has recently applied for the role of NHS Regional Dean for Genomic Education.

> “Digital technologies have transformed most sectors which affect our daily lives, from communications to transport, banking and entertainment, but not yet healthcare. This is now changing as electronic patient records and online services, as well as wearables, smartphones and apps, are beginning to have a positive impact on the NHS and its workforce.”
>
> **Professor Lionel Tarassenko**

5.0 Digital medicine

New digital technologies have the potential to transform how the NHS delivers care in the decades to come, for example, through faster and more reliable diagnosis of infectious diseases, empowerment of patients to monitor and manage their long-term conditions, promotion of health and wellbeing through personalised apps, and the delivery of care outside of traditional healthcare settings through remote monitoring.

In this Review, digital medicine is defined as digital products and services that are intended for use in the diagnosis, prevention, monitoring and treatment of a disease, condition or syndrome. This encompasses a broad range of technologies: telemedicine, smartphone apps, wearable devices, software used in clinical settings (such as e-prescribing), point-of-care tests, and extended reality technologies (including virtual reality and augmented reality). Some of these technologies are already having a positive impact on clinical practice and healthcare delivery, though adoption is uneven across the NHS.

Today, there are approximately 1.6 million searches for health information on the NHS Choices website each day. It is estimated that 60% of the people who use the internet to check a medical condition do not then go on to access a frontline service, reducing pressure on the NHS. Telemedicine is starting to be used across the NHS, offering a more convenient alternative to clinic consultations for patients who find it difficult, prefer not to or do not need to attend regular clinic appointments. The newly created NHS Apps Library contains over 70 apps and offers a trusted source of health apps for patients and the workforce. The new NHS App is due to be rolled out in early 2019. By 2021, it will allow people to upload data from their wearables and lifestyle apps, safely and securely, and consent for those data to be linked with their health records.

Advances in sensor technology and wearables are enabling remote monitoring outside of traditional hospital settings. Rapid diagnostic tests are revolutionalising access to HIV testing in accident and emergency, primary care and in the home. Virtual reality, a technology first developed for gaming, is now being used for a variety of healthcare applications, including mental health and live streaming of surgical procedures to teach the next generation of surgeons.

To realise the full benefits of digital medicine, the NHS will need to develop senior managers capable of leading on the digital agenda. Time and opportunity to increase the digital skills of the current workforce will be required, as will the ability to attract much needed up-to-date digital expertise. Equally, citizens, patients and families will have a pivotal role to play. Patient activism, such as #wearenotwaiting for patients with diabetes, exemplifies a growing trend in empowered patients demanding and taking greater control over their own care. Tackling digital exclusion while supporting the workforce to develop new skills and practices will be essential to ensure access and adoption across all socio-economic groups. Increased patient and public education programmes, as well as practical facilitation, will be needed to ensure that digital technologies do not increase health inequalities.

Regulators will have to ensure the quality, safety and accuracy of testing, and service managers will need to enforce the required service standards. It will be essential to build data connectivity into care pathways and electronic health records, within a fit-for-purpose governance framework.

5.1 The citizen and the patient

Digital medicine is increasingly empowering patients to manage their own health and wellbeing, transforming the traditional patient-clinician relationship. The growing availability of information online means that some patients research their conditions extensively. However, the quality of online health information varies widely, and so the NHS has a vital role to play in providing *trusted* information (DM1). Patients need to be confident that emerging digital technologies are safe and effective. Within NHS programmes of research, development and implementation, patients and end users should be involved in the co-design of new technologies, including the scoping of the required education and support (DM2).

Digital technologies can help empower patients to manage their own conditions. Diabetes provides a good example of how digital glucometers and smartphone-enabled wearable sensors enable self-management of the condition to be integrated into the activities of daily life. The NHS workforce needs to embrace a culture of working with increasingly informed and empowered patients. By working with patients to understand their personal requirements, healthcare professionals can provide guidance on how best to self-manage, while also recognising that digital technologies are not necessarily suitable for everyone. The adoption of digital health products should never be governed by the lack of access to these technologies (the ‘digital divide’). The NHS and associated organisations increasingly recognise this, with the resulting development of frameworks and toolkits,[112] including the NHS Widening Digital Participation agenda.[113]

Prevention should also be high on the agenda. Targeted public health campaigns should aim to provide education on modifiable risk factors, supported by long-term clinical studies to demonstrate how the use of digital technologies may help prevent conditions such as obesity and hypertension.

5.2 Healthcare professionals

Almost all areas of the workforce over the next 20 years will be affected by the adoption of digital technologies within the NHS and will need to be trained accordingly. At the heart of digital transformation is the opportunity to improve the quality and efficiency of interactions between patients, healthcare professionals and the healthcare system. To achieve this ambition requires substantial investment in the training of healthcare professionals, as well as the creation of new roles in data science, data security, ethics, human factors and implementation science. Investment in current staff should enable them to develop specialist digital skills, including the commissioning of digital technologies through continuous professional development (CPD), sabbaticals and secondments (DM3).

Analysis of large datasets extracted from electronic patient records integrated across primary and secondary care will lead to improved care, for example, through greater understanding of the relationship between treatment and patient outcomes. The potential of big data is driving the development of multi-disciplinary collaborations, with clinicians working alongside computer scientists and engineers. For example, Great Ormond Street Hospital Digital Research, Informatics and Virtual Environments (GOSH DRIVE) provides a physical space to enable such collaborations for innovation, development and rapid deployment of digital medicine within the NHS.[114]

The current workforce delivering care will need to know for whom, where, when and how digital technologies are able to improve the care pathway and health outcomes. They will also need to be fully cognisant of information and clinical governance issues, and be aware of any ethical implications. The strategy should include prioritising time and space to learn, and appropriate forms of CPD, using a combination of face-to-face training, e-learning and virtual/augmented reality.

To address skills gaps in the workforce, the NHS will need to establish new education programmes in digital healthcare technologies, such as Masters degrees and apprenticeships. Credentialing may allow staff to broaden and maintain their skills and experience. The specialist workforce will also need to learn new skills, for example, the commissioning of digital technologies. NHS Digital has highlighted the creation of the Federation of Informatics Professionals (Fed-IP) and Faculty of Clinical Informatics (FCI) as a means to recruit and retain much needed data science specialists within the NHS.

One of the key requirements we identified during this Review was the need to grow NHS capability to develop and assess the effectiveness of digital technologies. This includes the development of critical appraisal skills through knowledge of the standards and the regulatory environment. Clinicians will need the knowledge and skills to prescribe validated apps and digital products, advise patients on their use and interpret the clinical data that they generate. Mechanisms must also be put in place to enable the reporting of safety concerns, as soon as they arise.

5.3 Health system

Some areas of the NHS workforce have been early adopters of digital technologies, for example, primary care and intensive care. It is important that other services, such as mental health and acute medicine, should be in the next wave of adoption of these technologies. Digital technologies must be fully integrated into NHS care and prevention pathways, otherwise their introduction will risk fragmentation, duplication and inefficiency of care delivery.

The NHS will need to continue to develop a culture of innovation and learning. Digital leadership has been given the recognition it deserves with the appointment of the first NHS Chief Clinical Information Officer in 2016. The Digital Academy, launched in 2018, provides the first national learning programme in change management, leadership and clinical informatics, with a Postgraduate Diploma in Digital Health Leadership aimed at Chief Clinical Information Officers, Chief Information Officers and aspiring digital leaders from clinical and non-clinical backgrounds. This flagship programme, currently funded for three years, needs to be expanded to address skills gaps that exist in the wider workforce.

The NHS Entrepreneur training programme, Innovation Accelerator and Test Beds are excellent examples of how time and resources, including commercial skills and knowledge, can be provided to NHS staff who are keen to be digital innovators. These programmes need to be scaled up and become an accepted part of everyday practice to drive forward improved approaches to patient care and deliver increased workforce satisfaction.

To plan for the future workforce over the next two decades, the NHS will first have to increase the number of clinician, scientist, technologist and knowledge specialist posts with dedicated, accredited time to keep their skills up to date, and with the opportunity to work in partnership with academia and/or the health tech industry on the design, implementation and use of digital, AI and robotics technologies (AIR5/DM4). Secondly, the NHS will need to partner with professional, statutory and regulatory bodies, higher education organisations, educators and practitioners to identify the knowledge, skills, professional attributes and behaviours needed by healthcare graduates to enable them to realise fully the potential of an increasingly digital health service. This will necessitate the redesign of an agile and forward-looking undergraduate curriculum for healthcare professionals to equip graduates to work in the future NHS. Provision for extra places in graduate medicine programmes for BSc graduates with relevant skills, for example, in computer science or engineering, and equally the provision of an intercalating BSc for medical students to study engineering and computer science, will help to nurture cross-disciplinary skills.

NICE has developed an initial version of an evidence standards framework for digital health technologies, working in close collaboration with NHS England, NHS Digital, Public Health England, MedCity and other stakeholders. These standards have been designed to inform technology developers and evaluators about which types of evidence should be expected, taking into account the functions and intended use of the product and its overall economic impact. This framework will need to be embedded into the curricula for clinical training programmes.

The Medicines and Healthcare products Regulatory Agency's (MHRA) work on the regulation of digital technologies is becoming progressively more complex. Its workforce will have to be trained with the appropriate knowledge, skills and horizon-scanning capabilities for it to continue to be able to provide meaningful regulatory oversight. Working with regulators such as the MHRA, the NHS should therefore develop and commission courses to increase the number of specialists in the regulation and assessment of digital technologies (DM5).

Finally, programmes of research, development and implementation will be needed to develop and deploy disruptive digital technologies at scale across the NHS. A key priority should be to increase the flow of research talent into the NHS from relevant disciplines. NHS organisations should work more closely with existing academic centres of excellence, including the Engineering and Physical Sciences Research Council's (EPSRC) Doctoral Training Centres, and EPSRC Interdisciplinary Research Centres (IRCs), EPSRC Centres for Cyber Security, and the Alan Turing Institute.

“With over 1.2 million staff in England, the NHS is one of the largest employers in the world. It is vital that we empower NHS staff and patients to use emerging digital technologies, including nanosensors and wearables for early disease diagnosis and monitoring.”

Professor Rachel McKendry

5.4 Recommendations The Digital Medicine Panel recommends:

The citizen and the patient

- NHS online content should be a vital trusted source of health information and be resourced appropriately. (DM1)
- The NHS should expand research and development programmes, working closely with patients to co-create digital technologies and ensure that emerging technologies meet their needs. (DM2)

Healthcare professionals

- NHS organisations should invest in their existing workforce to develop specialist digital skills, including the assessment and commissioning of digital technologies, through the Digital Academy, continuous professional development (CPD), sabbaticals and secondments. (DM3)

Health system

New roles

- The NHS should create or increase the number of clinician, scientist, technologist and knowledge specialist posts with dedicated, accredited time, with the opportunity of working in partnership with academia and/or the health tech industry to design, implement and use digital, AI and robotics technologies. (AIR5/DM4)

Regulation and industry

- The NHS, working with regulators, should develop and commission courses to increase the number of specialists in the evaluation and regulation of digital technologies. (DM5)

Persona: Tom the nurse

Tom in 2009, aged 13:

Tom’s mum is a nurse and he would like to follow in her footsteps. He is interested in maths and science, but worries that his assessment scores will mean that he won’t be able to pursue and progress in a health career. However, he has impressed his teachers and peers with his teamwork, leadership and knowledge in school technology projects. Tom’s hobbies include sci-fi films and playing video games.

Tom in 2019, aged 23:

Tom left school at 18. He had a few other jobs before following his passion for healthcare and trying a career in nursing. Six months ago he joined the NHS as an Apprentice Nurse, undertaking a Level 6 qualification.

Tom likes respiratory nursing, and is developing an interest in exploring how digital healthcare technologies can improve workflow and support patients. He was delighted to be accepted to train at one of the NHS Digital Exemplar sites and to have a Digital Nurse Champion as his mentor.

Tom is excited about discussions of future nursing careers supported by new educational courses and learning resources, which help build skills with health data and technologies across healthcare professions. He has signed up to some of the new genomics and data science development courses.

Tom in 2029, aged 33:

Tom works in primary care. He has recently been appointed as a Consultant in Community Respiratory Care and is a partner in a community health centre, opportunities he would never have considered possible when leaving school.

Tom provides dedicated coaching sessions with newly diagnosed patients with asthma or COPD on how smart inhalers, apps and mobile devices can help them monitor and optimise their health. He co-designs personal health plans which incorporate genomic data, individual physiology and the patient’s desired clinical outcomes.

Tom’s multi-professional team receive patient alerts on clinical deterioration and medication adherence via a safe, AI-augmented remote consultation platform. The team triage patients promptly, nudge health behaviours and recommend new care plans where necessary.

Each month, Tom co-leads a two-hour ‘hackathon’ where a variety of collaborators come together to co-design and co-produce technological solutions for local problems affecting patient care and service need.

> Just as a microscope proved an invaluable tool in medicine and biology when it was developed and people learned how to use it, so AI will prove an invaluable tool as it is developed and people learn how to use it. It is a multi-purpose tool that can transform healthcare. But for this to happen, healthcare stakeholders (from patients to clinicians to policy-makers) need to learn sufficiently about AI and its capabilities to be able to harness and shape this emerging technology for their own benefit."
>
> **Professor Mihaela van der Schaar**

6.0 Artificial intelligence and robotics

The recent Academic Health Sciences Network (AHSN) state-of-the-nation publication highlighted two of the top five most important enablers of AI in the NHS as the *engagement* and *education* of healthcare professionals.[115]

The key determinant of whether the NHS successfully uses AI and robotics to transform healthcare will be the ability of the workforce to harness and realise the potential of AI and robotics.

The NHS should aim to develop a workforce able and willing to transform it into the world leader in healthcare AI and robotics. To achieve this, new opportunities must be created to recruit and retain people with the required technical skills. Significant changes to the roles and responsibilities of current and future NHS staff will also be needed.

6.1 The potential of AI and robotics technologies in healthcare

Healthcare is data intensive, combining not only huge volumes of disparate and complex sources of data, but also complex classifications and meanings. Advances in mathematics, computing power, cloud computing and algorithm design have accelerated the development of methods that can be used to analyse, interpret and make predictions using these data sources. AI encompasses a multitude of technologies, including but not limited to analysing and discovering patterns in data.

AI has the potential to transform the delivery of healthcare in the NHS, from streamlining workflow processes to improving the accuracy of diagnosis and personalising treatment, as well as helping staff work more efficiently and effectively.[116] With modern AI, a mix of human and artificial intelligences can be deployed across discipline boundaries to generate a greater collective intelligence.

Robotics encompasses the design, construction, operation and application of intelligent machines, and has been applied to medicine for more than 30 years. Robot-assisted surgery is now becoming more common in orthopaedic, laparoscopic and neurosurgical procedures. Miniaturisation of electronics to create smaller, smarter components (high-density batteries, high-performance microcomputing, sensors and actuators) is expanding the scope of robotics for healthcare.

Currently, most robots in healthcare operate with relatively low-level embedded AI. This will change over time, with robots becoming the 'hardware' that embeds, for example, machine-learning algorithms to perform a manual or cognitive task. As machines increasingly make decisions, there are ethical, legal and societal questions that need to be addressed.

A benefit of systematically implementing AI and robotics in the NHS will be the automation of tasks viewed as mundane or repetitive that do not require much human cognitive power. Additionally, AI or robotics may automate tasks that go beyond human analytical or physical capabilities. Both of these applications of AI will leave the workforce to focus on tasks considered 'uniquely human', especially human-to-human interaction and care.

6.2 Embedding an infrastructure for AI and robotics

Significant barriers to the deployment of AI and robotics within the NHS exist, not least NHS data quality, information governance, and a lack of expertise in AI and robotics.

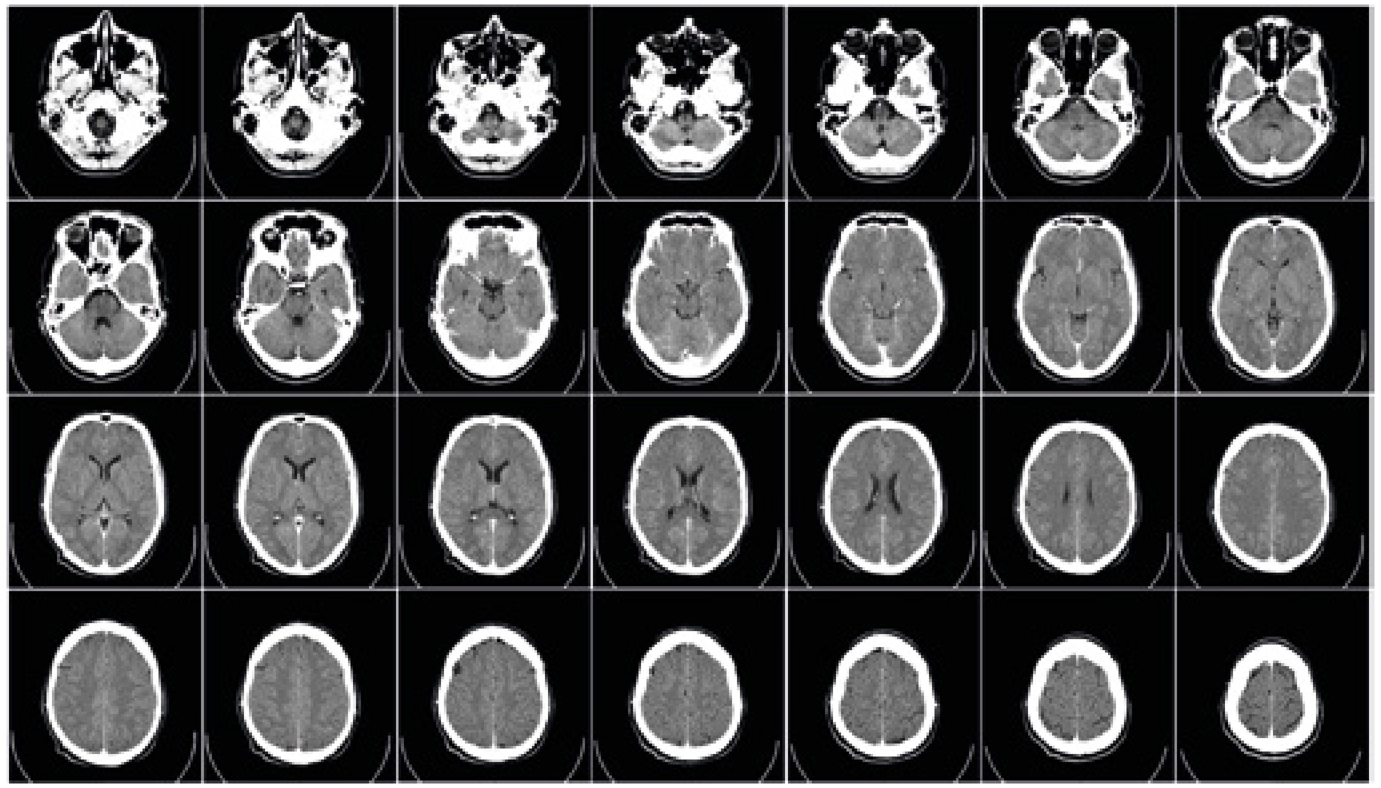
For data-driven and autonomous technologies to flourish the following are required:

- the digitisation and integration of health and care records;
- the provision of a binding 'code of conduct' (a core set of ethical principles and commitments) for those designing and implementing data-driven health and care technologies into the NHS;[117]
- guidance of 'evidence for effectiveness' which helps regulators, commissioners, procurers, managers and clinicians in the NHS to evaluate, regulate, purchase and use data-driven technologies.[9]

There is also the need for specific workforce learning in three key areas:

- knowledge and skills in data provenance, curation and governance;
- knowledge and understanding of the ethical considerations in using data-driven and robotic technologies for healthcare;
- critical appraisal of digital healthcare technologies – understanding how the technology works, including the statistics underpinning machine learning and its outputs, and the potential biases.

This knowledge and these skills are essential for the whole NHS workforce. Continuing professional development throughout each individual's career is essential to reinforce and update learning, complemented by deeper dives into specialist training where appropriate.



6.3 The citizen and the patient

Over the next five to 10 years it is likely that there will be greater public expectation that the NHS will increasingly use AI and robotics technologies in healthcare. Patients should be involved from the beginning in the design and implementation of AI software for healthcare, ensuring that their needs and preferences are reflected in the co-design process (AIR1). A fully integrated, digitised and remotely accessible health and care record should also become available within the next decade. This will provide the platform for the integration of AI-based technologies delivering user-friendly, real-time information on personal health data and empowering patients to manage their own health or seek appropriate health support.

Some patients are already using AI technologies through their smartphone to monitor and manage their health. AI-powered chatbot technologies that use NLP provide patient and clinician-friendly interfaces for monitoring an individual's health.[60] AI technologies will also allow patients to self-monitor conditions presenting with direct or translatable visual signs.[71] Clinicians and patients will benefit from smarter triage, which will reduce the volume of clinical workload and free up time for patients with the greatest and most immediate need.

Rehabilitative and wearable robots, including prostheses, exoskeletons and brain-machine interfaces, deployed in hospitals and in the community will provide advanced functionality to patients with physical disability. As the number of AI and robot technologies increases, there is a risk that choice and the pace of change overwhelm patients and clinicians. This will require the NHS to provide access to systems, which could be AI-based recommender systems, to help guide staff and patients as to which technologies to adopt to best assist their specific needs.

Patient benefit must remain the driving criterion for AI and robotics design and use, and the workforce must be confident in their decisions about when and how human interaction must take priority over AI-human interaction.

6.4 Healthcare professionals

AI and robotics will support clinicians in delivering safer, higher-quality care. Machine learning-enabled early warning systems that alert clinicians to patients at risk of deterioration in the hospital perform better than existing clinical risk scores.[85] Deep-learning technologies designed for automated image interpretation have already shown expert-level performance in medical image analysis. Radiology, pathology and ophthalmology are frequently cited as the disciplines most likely to be influenced by these AI tools, due to the availability of digitised data and interoperability standards within those disciplines. The spread of digitisation, supported by appropriate infrastructure, will lead to AI changing clinical diagnostics, and this will benefit all healthcare professions.

AI technologies and automation can also help the NHS manage the increasing demands on its staff. One of the game-changing uses of AI will be the automation of administrative processes. Currently, between 15 and 70 per cent of a clinician's working time is spent on administrative tasks.[118] Well-designed AI can reduce administrative burdens, giving clinicians more time for patient-clinician interaction and highlighting the positive impact of AI technologies.

For clinicians to benefit fully from AI and robotics technologies, four conditions have to be met: time and willingness to adopt new technology; an understanding of the technology; well-designed technology meeting user need; and workplace support to maximise the potential of the technology. Clinicians and healthcare scientists who are passionate about progressing the adoption of digital healthcare technologies and keen to develop a specialist interest should be valued and supported to do so. Flexible ongoing training and career opportunities should be made available to those clinicians and healthcare scientists.

There is a need to develop educational resources to educate and train healthcare professionals in: health data provenance, curation, integration and governance; the ethics of AI and autonomous systems/tools; and the critical appraisal and statistical interpretation of AI and robotics technologies (AIR2). Joint learning programmes involving components from computer science, robotics and engineering should be made available to healthcare students at both undergraduate and postgraduate levels. These courses could be designed in collaboration with university computer science and engineering departments, and hosted online. New apprenticeship and Masters schemes relevant to data science, AI and robotics in healthcare should also be developed.[119]

Other healthcare professionals, such as prosthetists, orthotists, physiotherapists and occupational therapists, will require specialist training in personalised treatment and rehabilitation planning. The NHS will need to attract, recruit, integrate and develop individuals with the core STEM knowledge base and skills for robotics – for example, mechanical engineering.

6.5 Health system

The recruitment and training of greater numbers of professionals with computer science, data science, engineering and other relevant expertise is critical to reducing the AI and robotics 'skills gap' in the NHS. With the current boom in AI and data science industries, graduates with expertise in these fields are highly sought by industry employers; therefore the NHS needs to be competitive in recruiting talent. It should explore innovative options to attract global technical talent to design AI and machine learning solutions to some of its most pressing clinical and operational challenges. It should be possible to leverage the NHS' global reputation and integrated datasets to attract skilled experts from the global community of data scientists (AIR3). Through opening up anonymised, well-curated and ethically governed data platforms, the NHS could offer machine learning competitions as a precursor to clinical testing and implementation.

To recruit and retain staff with AI domain knowledge, the NHS could also make itself an employer of choice by offering flexible jobs and clear career pathways. AI specialists working in the NHS should be seen as valued members of clinical or clinically led academic teams in which shared learning can enable them to design solutions to clinical and ergonomic problems. Long-term roles that share time between the NHS and industry/or academia could be created, helping to attract technical talent to address the challenges of healthcare, with individuals bringing innovative technical knowledge and skills into the NHS throughout their careers. Attracting the right talent through a national programme of 'Industry Exchange Networks' would benefit the NHS (AIR4).

The NHS should increase the overall numbers of clinicians, as well as scientists, technologist and knowledge specialist posts, with dedicated, accredited time to keep their skills up to date and with the opportunity to work in partnership with academia and/or the health tech industry on the design, implementation and use of digital, AI and robotics technologies (AIR5/DM4).

Planning and commissioning of local services will vary, and autonomy should be preserved to leverage the best use of workforce numbers and talent in a particular region. AI can also be used to monitor and predict public health trends, analysing data in real time, and identifying initiatives with positive and negative impacts on population health. Public health physicians and epidemiologists with higher-level training in data science will be needed to develop effective prevention and prediction strategies.

To support local initiatives, skills in horizon scanning and workforce strategy development will need to be strategically allied with an understanding of how health data and technology are best used to support and improve working practices.

> "Artificial intelligence is a tool, and like any other healthcare tool, NHS professionals must be trained to use it in the right manner and context with confidence. The fundamentals of AI and machine learning are based on digital data curation, statistics and probability, and it is these areas that the NHS staff of today will need to master in order to benefit from the tools of tomorrow."
>
> **Dr Hugh Harvey**

6.6 Recommendations
The AI and Robotics Panel recommends:

The citizen and the patient

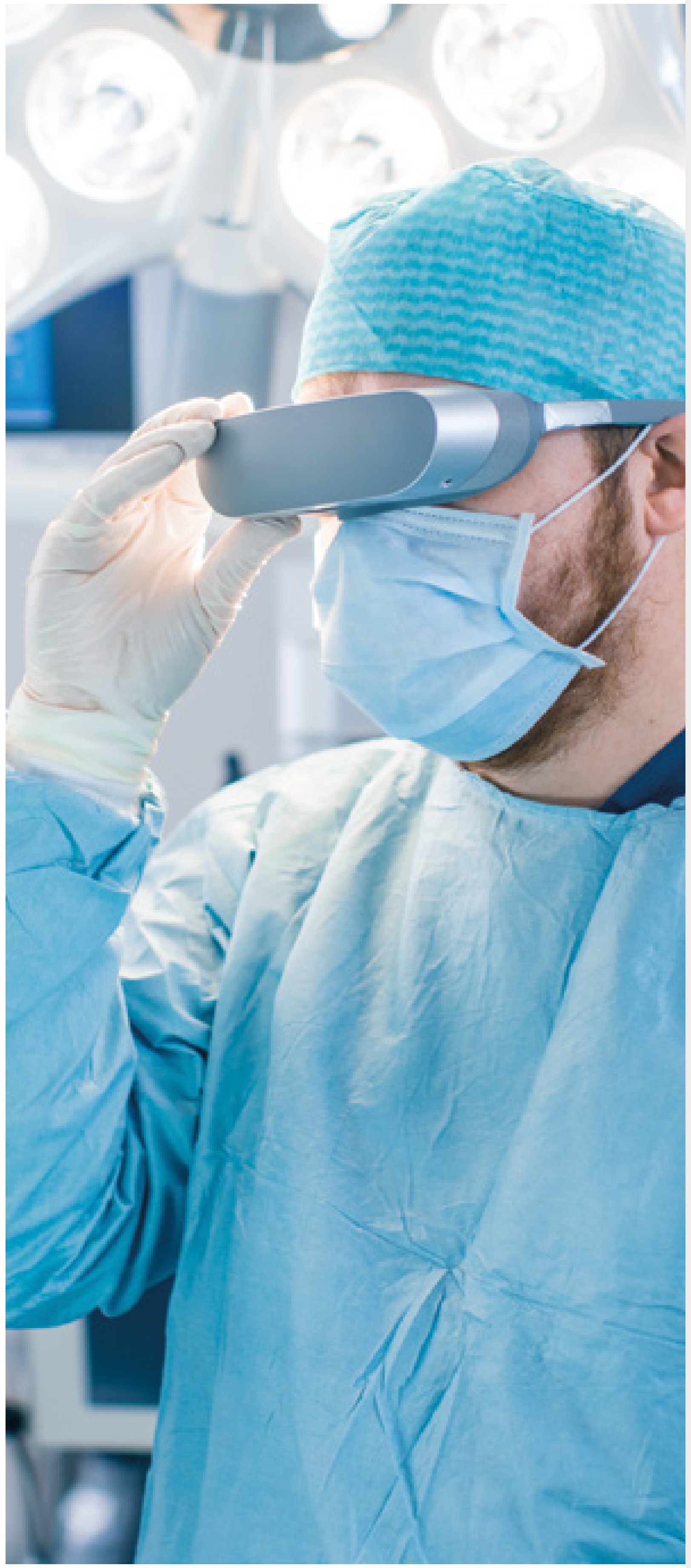
- The NHS should ensure that patients are involved from the beginning in the design and implementation of AI software for healthcare, with their needs and preferences reflected in the co-design process. (AIR1)

Healthcare professionals

- Educational resources should be developed to educate and train all healthcare professionals in: health data provenance, curation, integration and governance; the ethics of AI and autonomous systems/tools; critical appraisal and interpretation of AI and robotics technologies. (AIR2)

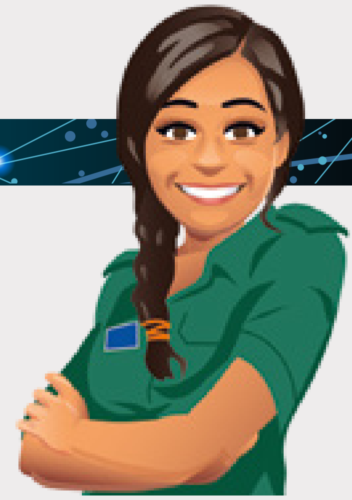
Health system

- The NHS should leverage its global reputation and integrated datasets to attract skilled experts from the global community of data scientists. (AIR3)
- Given the national shortage and competition for AI specialists, there should be a national programme of 'Industry Exchange Networks' that would benefit the NHS. (AIR4)



Persona: Salma the paramedic

Salma in 2009, aged 38:



Salma is a psychology graduate and worked for various medical charities for 10 years before deciding to pursue a new career. She remained very interested in working in the healthcare field.

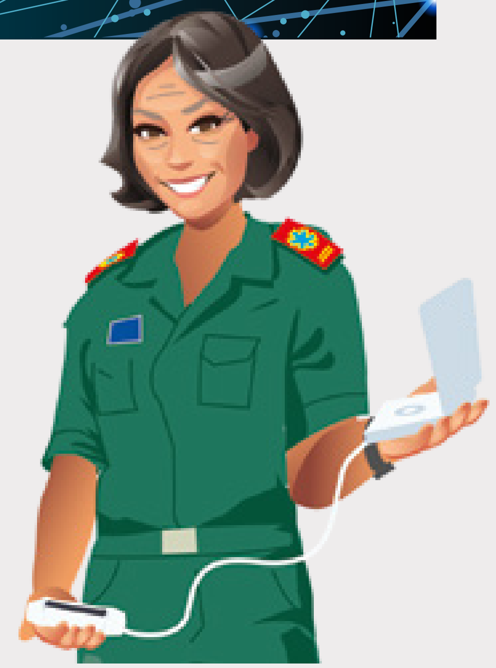
Following completion of a two-year Level 3 vocational course, she graduated with a degree in paramedic science and recently qualified as a paramedic. Salma's training contained very little about how paramedics may benefit from evolving technology throughout their careers.

Salma in 2019, aged 48:

Salma, a senior paramedic, is a team leader in a large city. She is frequently frustrated by the lack of patient information accessible at the scene of an emergency. Furthermore, she would like to be able to provide A&E departments with better real-time information on the patients she is treating, in advance of their arrival at A&E department, in order to streamline the handover and treatment process.

Salma is determined to increase her knowledge and skillset to deploy health technologies at work. She has researched how digital health tools could improve healthcare, but has yet to see significant change or investment in technology that improves her working life. Salma participated in the comprehensive NHS consultation process aiming to capture workforce opinions on their competencies and challenges in adoption of technology.

Salma in 2029, aged 58:



Salma has seen her work transformed by the impact of digital technologies. She is transported in an autonomous ambulance that drives the most efficient route to an emergency, improving response times. On receiving the patient details, Salma gains immediate access to the integrated electronic patient record that is projected onto a digital display, providing information on medical history, allergies and pharmacogenomics profile.

Salma's smartwatch and smartphone, enabled with mobile vital signs and an ECG reader, and AI-augmented ultrasound scanner, facilitate real-time monitoring and diagnostics. All the data captured are immediately transmitted to the hospital-based team who, with the help of machine learning algorithms providing decision support, can advise, plan and prepare any additional treatment prior to the patient's arrival.

Salma receives regular education and training updates on innovation in clinical practice hosted within clinical skills hubs, which model how technology and health data can best be used to improve patient care.

7.0 Healthcare economics, productivity and the gift of time

Technological solutions successfully being adopted in many sectors of industry and commerce face similar workforce challenges to those of the NHS. Yet the role of technology as a driver of productivity is a matter of much debate.

> Technological innovation has been critical to increasing productivity growth in the past, but today there is disagreement around the impact current technological innovation is having on the economy."[120]

Developments in robotics and AI systems, as highlighted in the previous chapter, are making it possible to automate activities that previously could only be done by humans, and to assist workers with tasks that cannot be fully automated. These systems are used across the UK economy to automate both physical and knowledge-based work. They have the potential to cut costs and increase productivity, bringing economic benefits.

Taking as exemplars some of the digital healthcare technologies described in Chapter 3, this Review has sought to draw out some high-level messages from them and highlight lessons that may be learnt. The selected exemplar technologies can all be implemented at scale.

> The pace of adoption will depend on factors such as the nature of the technology itself, staff costs including training, initial investment required, public perception, and regulation."[121]

7.1 Impact on patients

There will be a spectrum of effects depending on the technologies deployed. Many new apps enable self-monitoring and self-management to lower modifiable risks of current or possible future disease (see **Chapter 5**). Polygenic risk scores will soon be used to predict future risk of common conditions (see Chapter 4), such as coronary heart disease, type 2 diabetes, breast cancer, prostate cancer and inflammatory bowel disease. This knowledge will encourage some high-risk individuals to adopt risk-lowering lifestyles, go for regular screening and take preventative medication, such as statins, where appropriate. With other digital healthcare technologies, the effect on patients will be as a result of improved treatment. For example, machine learning applied to medical image analysis (see Chapter 6) has the potential to improve post-stroke care through more accurate analysis of CT and MRI scans. As a result, patients are likely to spend more time in better health.

The ability of digital technologies to streamline access to services and reduce the number of unnecessary visits by patients to hospitals or GP surgeries cannot be overstated. Avoiding just one hospital outpatient appointment has been estimated to save the patient on average £36 in time and travel costs, while similar figures for a primary care appointment are on average £17 per patient.[122] The burden of these costs is disproportionately carried by those least able to afford them.

7.2 Impact on workforce and healthcare system

Technologies can be divided into those that augment existing care and those that might have the capacity to transform care. With the former, the technology allows healthcare professionals to deliver better care, for example, through improved stratification or personalisation of care. With the latter, care is transformed as a result of meeting or eliminating a need that previously could not be managed.

The growth of sub-specialism and new workforce groups, for example, highly-skilled interventionists in specialist centres for clot removal following a stroke, also reduces the need for more traditional skillsets. This trend is likely to continue, and the adoption of digital technologies that focus on earlier identification and management of conditions will also shift care from secondary care to primary care.

The wider impact on the health and social care system can be summarised as: shifts in the balance of care; centralising highly specialised tasks (as has been seen in stroke and emergency care) and decentralising less specialist tasks; and long-term shifts in the patterns of need and therefore services.

7.3 Potential impact of digital healthcare technologies on workforce productivity

The figures in the examples below are high-level estimates based on **hypothetical scenarios** to illustrate the potential scale of impact from digital healthcare technologies on a subset of NHS services, assuming that the relevant technology matures and is adopted throughout the NHS in England. Given the uncertain nature and timescale of technological developments, and the challenge of projecting their impact over 10 to 20 years based on today's limited available evidence, it is stressed that the figures given below are no more than first-order approximations – they were produced by blending case study findings with expert opinion, published evidence and publicly available data. They nevertheless provide us with an insight into what the future might look like in the decade ahead, and show the potential that digital healthcare technologies have for giving time back to healthcare professionals.

7.3.1 Telemedicine (Example 1 in Figure 1 – Chapter 3): Brighton and Sussex University Hospital Trust Virtual Fracture Clinics

Virtual fracture clinics, as described in Chapter 3, have been shown to be effective, improving several key clinical performance parameters and potentially providing substantial cost-savings for local Clinical Commissioning Groups (CCGs).[123] If these clinics were introduced nationally, they could potentially deliver very large savings for the NHS.

Annually, there are approximately **7.6 million** trauma and orthopaedic outpatient appointments[124]

At least **50%** of fracture clinic appointments could be virtual[93,125]

Virtual fracture clinic appointments reduce the total number of appointments needed by **15%**[126]

If scaled up, this would equate to a time saving approximating **570,000** 15-minute outpatient appointments

Equivalent annually to approximately **142,000** hours of outpatient clinic time

80 healthcare professionals' time back for clinical care

7.3.2 Smartphone apps (Example 2 in Figure 1 – Chapter 3): myCOPD app

Chronic Obstructive Pulmonary Disease (COPD) is a common long-term respiratory condition and one of the top five causes of death in the UK. myCOPD is an app that integrates education, symptom reporting and pulmonary rehabilitation to improve self-management of COPD. Patients who use the app manage their condition more effectively and have fewer unplanned hospital admissions.[127]

Around **835,000** people in England alone are currently diagnosed with COPD[128]

Per year, COPD accounts for approximately **115,000** emergency admissions

880,000 hospital bed days[128]

myCOPD

Users of the myCOPD app saw emergency admission rates reduce by approximately **19%**[127]

Not all COPD patients will be able or willing to use the app, for example, those with severe COPD or those who use supplemental oxygen.

If 50% of patients with COPD used myCOPD or an equivalent app, reduced admission rates for acute exacerbations would equate to a minimum approximate annual saving of **84,000** bed days

150 nurses' time back for clinical care

7.3.3 Smartphone apps (Example 2 in Figure 1 – Chapter 3): GDm-Health app

Conventional gestational diabetes mellitus (GDM) monitoring involves the use of a paper diary and fortnightly visits to a hospital clinic. The GDm-Health app facilitates self-monitoring and tracking of the progression of diabetes by specialist midwives remotely. The app provides secure communication between women and their healthcare team and potentially reduces the need for clinic visits at the same frequency. Women using the app have been shown to improve their blood glucose control and require fewer clinic visits.[129,130]

There are approximately **80,000** women with GDM in the UK

GDm-Health

Users of the GDm-Health app require up to **two** fewer clinic visits on average during their pregnancy[131]

Annually, this equates to a maximum of

160,000 outpatient appointments

40,000 hours of outpatient clinic time

20 consultant diabetologists' time back for clinical care

7.3.4 Remote monitoring (Example 3 in Figure 1 – Chapter 3): Airedale and Partners Enhanced Health in Care Homes Vanguard

The Airedale Digital Hub provides tele-consultations between nursing and residential homes and experienced clinicians, 24 hours a day, seven days a week. The hub assesses and triages all requests for clinical advice and consultation, including GP visits, and refers the patient for the most appropriate care. Figures for 2017 suggest that 90% of consultations resulted in patients remaining in their nursing/care home, approximately 38% of GP referrals could be saved, and ambulance conveyances decreased by up to 40%.[132]

There are approximately **295,000** A&E attendances for care home patients annually in the UK

268,000 patients conveyed by ambulance

approximately **250,000** admissions[133,134]

17 days[135] average length of stay

Remote monitoring supported by a Digital Hub has the potential to prevent approximately **40%** of ambulance conveyances, A&E attendances and hospital admissions

Annually, that is approximately

107,000 ambulance conveyances

118,000 A&E attendances

102,000 admissions

1,740,000 bed days

3,164 nurses' time back for clinical care

Annually, the avoided activity is the equivalent to approximately

218,000 hours of A&E consultation time

124 doctors' time back for clinical care

53,000 hours of ambulance time

30 paramedics' time back for clinical care

This has to be set against the numbers of Digital Hubs which would need to be set up nationally, and the number of staff needed to run these hubs 24 hours a day, seven days a week.

7.3.5 Speech recognition (Example 5 in Figure 1 – Chapter 3): South Tees Hospital NHS Foundation Trust Accident and Emergency

South Tees Hospital NHS Foundation Trust A&E department introduced clinical speech recognition as a way of dealing with the rising volume of clinical documentation resulting from increasing patient numbers. The technology improved the ease and speed with which clinical documentation was completed, as well as the quality of documentation. When compared with handwriting, typing or traditional dictation, the technology was found to save three minutes per patient, freeing up vital time for clinicians in A&E to see and treat patients.[136]

Each year there are approximately

24 million A&E attendances[137]

63 million outpatient attendances[138]

340 million GP consultations[139]

Using a conservative estimate of **one minute** saved per patient consultation

Annually, that equates to approximately

- **400,000** hours of A&E consultation time ▷ **230** A&E doctors' time back for clinical care
- **one million** hours of outpatient clinic time ▷ **600** hospital doctors' time back for clinical care
- **5.7 million** hours of GP consultation time ▷ **3200** GPs' time back for clinical care

7.3.6 Automated image interpretation (Example 7 in Figure 1 – Chapter 3): Diagnostic support in Radiology

Automatic image interpretation using deep learning for the automated detection of breast cancer has been described as a use case in Chapter 3. The aim is to improve the accuracy of screening while benefiting the workforce by eliminating the need for a second reader of the mammography scans.[140]

Radiologists conservatively spend at least **60%** of their time reviewing images.[141]

Eliminating the need for a second reader represents a **30%** reduction in the time spent reviewing mammograms.

If we assume that what has been achieved with mammography can also be applied to a large extent to other medical images reviewed by radiologists, **AI methods such as deep learning have the potential to reduce the time radiologists spend reviewing images by 20%**[141]

Each year there are approximately **41 million** medical images taken and read by the UK NHS workforce of **4,204** radiologists.[142, 143]

Annually, the potential impact of AI technologies on diagnostic radiology equates to the equivalent of approximately

- **8.2 million** images
- **890,000** hours of radiologist time
- **500** radiologists' time back for clinical care

8.0 Organisational development

The NHS is complex, with multiple roles, functions and needs. Leading change in such a system can be logistically challenging, even for straightforward problems.

The challenges associated with introducing digital healthcare technologies are similar to those of any major change initiative. Delivering a technological future requires investment in people, building digital skills and leadership capabilities, and a change in the organisational culture. Work is already under way in the NHS on the Building a Digital Ready Workforce programme, enabling staff to identify their digital readiness and meet their training needs (OD3).[144]

Better recognition of the enablers of change can help our understanding of the slow and fragmented level of adoption of digital healthcare technologies in parts of the NHS. Time is required for the majority of people to accept the merits of, and adopt, any innovation.[145] Time will also be needed for digitisation to deliver efficiency gains – a phenomenon known as the 'productivity paradox'.[32]

Introducing new technologies to support patient care and the workforce needs to be seen as change management, with the technology itself simply the tool to enable change. Most patient care pathways are multifaceted, involving staff with deeply held personal, social and institutional beliefs and practices. To be successful, technology-based change policies need to acknowledge and seek to understand these beliefs and practices. This requires organisations to focus on the following enabling factors: a culture of innovation; prioritising people; an agile and empowered workforce; leadership; effective governance; and investment.

8.1. An open and inclusive innovation culture

Organisational culture is a major factor affecting the speed and frequency of innovation.[146] NHS organisations need to demonstrate agile and dynamic responses to innovation with an open, inclusive culture, and with a focus on patient safety and quality of service.[147] The latter, however, is not an excuse to halt development or investment in the infrastructure and services needed to deliver the digital future.

The 'test and improve' approach to implementation through prototyping and iterative learning allows timely trialing of innovation and new pathways using real-time feedback. The clinical teams required to adopt technology-enabled change are likely to be non-hierarchical, self-organising, multi-disciplinary teams in which colleagues have equal status and responsibility.

Effective knowledge management is essential to enable the spread and adoption of innovation, with lessons from early adoption shared widely (OD6): an innovation culture is dependent on a learning culture. The NHS must build a reputation as a learning organisation that values and enables the transfer of learning about successes and failures (OD5). This can only happen with the creation of new senior knowledge management roles.

Virtual networks and communities of practice will help reinforce learning by connecting people interested and involved in technology-based innovation. Interested healthcare staff should be supported to undertake these activities and encouraged to develop new collaborations to lead future innovation.

8.2. Prioritising people

Participatory design principles have led to successful wide-scale IT implementation, for example, the Government Digital Service (GDS).[148] When redesigning or implementing services, NHS organisations should focus on 'what matters' to people. Technological solutions are adopted, diffused and sustained more successfully if the patients and healthcare staff using them have built them together.[149] Patients, citizens and staff should therefore be encouraged to work and learn together to co-design solutions and, where appropriate, co-deliver these (OD1).

Time for staff to learn and work together is likely to require increased investment, offset by the longer-term benefits. Early, effective and sustained staff engagement at all levels, especially front-line staff, is a pre-requisite for technology-enabled transformational change to be successful.

8.3. An agile workforce

The combination of rapid technological advances and the changing healthcare needs of the UK will cause a degree of disruption, requiring the workforce to be agile. Roles will become more fluid and role boundaries may blur.

The entry of millennials into the workforce has already resulted in changing expectations around work-life balance, flexible careers, rewards and incentives, relationships with employers and the use of technology. With increasing digitisation and digital literacy, the social and emotional skillset of the workforce will become increasingly important.[150] Adoption of innovative technologies that automate repetitive and administrative tasks should also give the workforce more time to make use of cognitive skills.

Most NHS staff will need a basic knowledge of change management for their own personal development and to contribute to the wider system. NHS organisations will need to recruit people with an appreciation of technological innovation and skills in implementing change while managing uncertainty. These staff will need to be supported to learn from the setbacks that come with any change, technology-related change being no different.

The NHS needs to attract new talent and shape new career pathways. Opportunities to work together with academic institutions and industry will become more common. The scope for mutually beneficial joint appointments should be explored (OD8).

8.4. Leadership

In the digital era, the NHS needs more than ever to encourage the development of visionary leaders who can effect change across the system through collaborative approaches. The NHS Leadership Academy has an important role to play here. Change initiatives themselves are likely to produce 'emerging' leaders, who have the insight, energy and impetus to drive change. Developing leadership talent requires training schemes (including coaching and mentoring) to be available. Digital leaders should be capable of understanding the role of data, information, innovation and technology in their local organisation, now and in the future.

Enabling the NHS to adopt and diffuse digital healthcare technologies safely, effectively and efficiently at scale and across geographies requires Board-level leadership focused on clinical outcomes and on promoting effective and consistent staff engagement (OD4).[3]

System leaders will need to take a strategic perspective on research and innovation in science and technology, with new senior roles being created to horizon-scan, advise on the opportunities offered by digital healthcare technologies and identify local skills gaps (OD2). The NHS Digital Academy is already supporting the most senior leaders. It is clear from our Review that a much greater proportion of the workforce will need these enhanced leadership skills.[151]

NHS organisations should use validated frameworks to implement technological solutions and ensure staff are trained to use these (OD7). There are several frameworks available, including those specifically developed by NHS England[152] and NHS Improving Quality,[153] but few focus on technological systems change within the NHS. The NASSS (Non-adoption, Abandonment, and Challenges to the Scale-Up, Spread, and Sustainability) framework has been developed to help understand why there is non-adoption of many technological innovations and to inform the planning and implementation of technology-focused change projects (see NASSS case study below).[154]

8.5. Establishing effective governance arrangements for digital health

Regulation is intended to protect patients and society and reduce the risk of harm. Clinicians and patients must be able to trust that technologies approved for use in the NHS meet robust standards set by regulators.

The challenge in regulating digital healthcare technologies is significant and the regulatory response continues to evolve. Collaboration between individuals leading change and the regulators is essential to build a consensus on how a particular technology is regulated. The collaborative partnership will need to be stretched to include industry when potential solutions to new regulatory challenges are needed. Regulation should be an enabler, not a barrier to innovation.

The NHS should work with stakeholders across sectors to review the regulation and compliance requirements for new digital healthcare technologies, including the provision of guidance and training on cyber security, data privacy and data anonymisation, learning from the experience of other international healthcare systems (OD9).

8.6 Investment

The benefits of investment in digital technologies are initially seen in improved safety and quality; it can take up to 10 years to realise cost savings.[32] Investment in IT systems (hardware, software and connectivity) will continue to be essential. The NHS will need to invest in training people with the right professional skills to support this change. Clinical staff, patients and the public will need to have confidence that the NHS has effective systems and processes not only to protect patient data, but also to enable its ethical use in the development of new methods and algorithms to improve patient outcomes.

NHS organisations need to give leaders enough time to plan, build relationships and evaluate change, and to allow staff time away from clinical work to engage in co-design, to participate in collaborative peer-networks and develop leadership skills.

8.7 Recommendations
The Organisational Development Working Group recommends:

The citizen and the patient

- NHS organisations must ensure that patients, citizens and staff are involved in the co-design of transformation projects, particularly in identifying how digital healthcare technologies can help to improve both patient experience and staff productivity. (OD1)

Healthcare professionals

- Senior roles should be developed with responsibility to advise on the opportunities offered by digital healthcare technologies and identify local skills gaps. (OD2)
- Healthcare professionals will need to access training resources and educational programmes in digital healthcare technologies to assess and build their digital readiness. (OD3)

Health system

- Each organisation should assign Board-level responsibility for the safe and effective adoption of digital healthcare technologies at scale, with a focus on clinical outcomes and on promoting effective and consistent staff engagement. (OD4)
- NHS Boards should take responsibility for effective knowledge management to enable staff to learn from experience (both successes and failures) and accelerate the adoption of proven innovations. (OD5)
- The NHS should strengthen systems to disseminate lessons from early adoption and share examples of effective, evidence-based technological change programmes. (OD6)
- NHS organisations should use validated frameworks to implement technological solutions and ensure staff are trained to use these. (OD7)
- The NHS should support collaborations between the NHS and industry aimed at improving the skills and talent of healthcare staff. (OD8)
- The NHS should work with stakeholders across sectors to review the regulation and compliance requirements for new digital healthcare technologies, including the provision of guidance and training on cyber security, data privacy and data anonymisation, learning from the experience of other international healthcare systems. (OD9)

Case study:

Virtual outpatient clinic development: using the NASSS framework[154]

Barts Health NHS Trust and the University of Oxford are working together to develop video-based remote consulting as part of business as usual. The Diabetes service at Barts has been using Skype for outpatient consultations since 2011 for patients with challenging social circumstances and a history of missed appointments. Initial studies have shown high acceptance rates among patients with reduced 'did not attend' rates and improved self-management.[155, 156] However, extending the service model to other outpatient clinics across the Trust has proved challenging. A research study[157] was undertaken to understand and try to overcome these challenges, focusing on the experience of patients and staff, the organisational changes needed and the influence of the wider national context.

The research team applied the NASSS framework to understand and inform the process of introducing and scaling up video-based consultations. This framework involves seven interacting domains: (1) the illness or condition, (2) the technology, (3) the value proposition, (4) individual adopters (staff and patients), (5) the organisation, (6) the external context, and (7) emergence over time. Complexity in one or more domains makes embedding technology harder. Video-based consultations worked best for predictable, low-risk conditions, with dependable, fit-for-purpose technology whose use was easily aligned with other organisational processes. Interdependencies across different routines and systems required cross-departmental collaboration and organisational change. A rapidly changing political and economic context with continually emerging technologies required identification and adaptation to these external changes to ensure sustainability. A 'Video Consultation Unit' was established to horizon-scan and promote knowledge-sharing within the Trust. The service model is now scaled up to over 15 clinical teams across the Trust.

Persona: Sarah the doctor

Sarah in 2009, aged 26:

Sarah is a paediatric specialist trainee and loves her work. She has started to use a smartphone in her personal life, but has no access to mobile technology at work and is frustrated by having to rely on outmoded technology, especially fax machines, and time-consuming paper records. Communication with her peers and multi-professional colleagues is disjointed, and has caused patient safety incidents.

Sarah in 2019, aged 36:

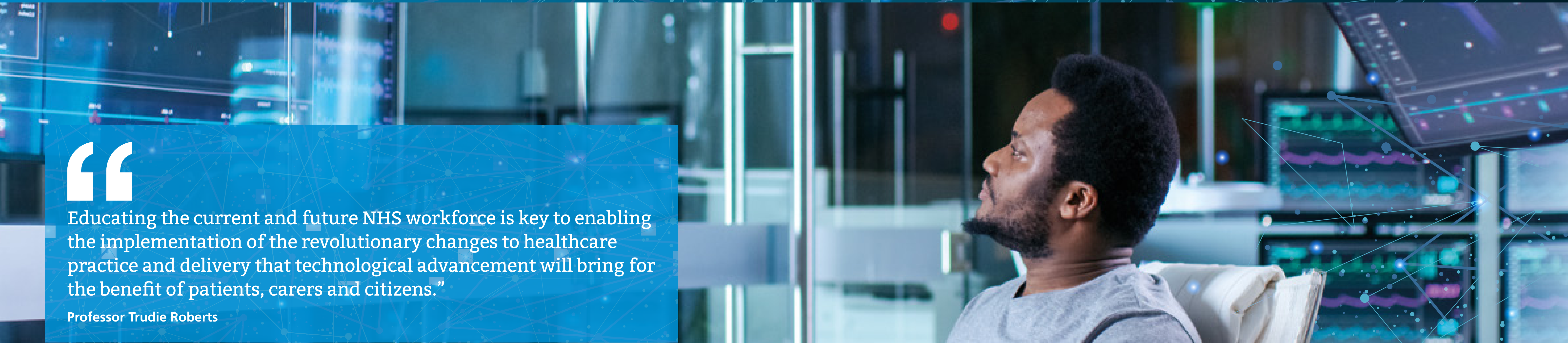
Sarah is a paediatric consultant with a specialist interest in metabolic medicine. She has completed a Masters degree in Medical Education and modules of the Genomics Education Programme. Sarah observes that despite schemes like the NHS Clinical Entrepreneur Programme, adoption of innovation in the NHS is variable and slow.

Although hospital-wide electronic prescribing and a new electronic patient record have been introduced, Sarah is still frustrated by needing to use fax machines and bleeps. She wants to use more streamlined, intelligent communication with colleagues and patients, which maximises the amount of time she can spend with patients. However, there are still concerns in her Trust about the data governance and General Data Protection Regulation for social media such as WhatsApp. Sarah is encouraging her Trust Board to be forward-thinking and review some of the NHS Global Digital Exemplars' initiatives in health information integration.

Sarah in 2029, aged 46:

Sarah is a consultant with a portfolio career that combines clinical work in paediatrics with a national coordinating and oversight role within Genomics England.

Most of her patients have their whole genome sequenced at birth, allowing Sarah a much greater understanding of her patients' pathology. Sarah's clinical team now includes bioinformaticians and computer scientists – who bring expertise and learning from their secondments in industry. The whole team benefits from access to integrated, interoperable electronic patient record systems supported by AI technologies. Machine-learning algorithms process the outputs from wearable sensors that remotely monitor metabolic markers to predict patient health trajectories and model personal care plans. As a result, early intervention, followed by personalised treatments, have markedly improved outcomes in conditions such as diabetes. Furthermore, cloud-based educational tools provide accessible 'just-in-time' learning resources that enable clinicians, patients and their families to better understand and manage their conditions.



> "Educating the current and future NHS workforce is key to enabling the implementation of the revolutionary changes to healthcare practice and delivery that technological advancement will bring for the benefit of patients, carers and citizens."
>
> **Professor Trudie Roberts**

9.0 Providing a learning environment for education and training

Adoption of digital healthcare technologies requires an effective culture of learning at every level that enables the workforce to reframe their knowledge within an increasingly technology-driven world.

Resistance to change and scepticism about technology are well-recognised barriers to progress[158, 159] – both can be overcome by a motivated and enthused workforce. For sustained and effective adoption, individuals need to see digital healthcare technology solutions in the context of their own clinical practice and of quality improvements in care.

9.1 A culture of learning

Key ingredients of the learning culture are: encouraging lifelong learning, openness to collaboration and effective co-design and a greater understanding of human intelligence.

9.1.1 Encouraging lifelong learning

The NHS needs to nurture growth mindsets throughout the workforce. Someone with a growth mindset believes that intelligence is developed through learning. Self-efficacy is key to turning learning into action and onwards towards longer-lasting change in behaviour. It involves making accurate, evidence-based judgements about current levels of knowledge and understanding, and matching these to the levels required. This starts with the recognition that change is required. To ensure lifelong learning can happen, staff require the following: dedicated time outside of their normal duties to develop and reflect on their learning; learning activities that are proactive rather than reactive; a strong workplace learning infrastructure; and a workplace reputation for training and support (E1).

Motivated staff have belief in their ability to undertake transformation, perceive it to be important and believe that they have control over the outcomes.[160] The NHS lacks receptivity to bottom-up clinical innovations and ideas.[161] Participation in initiatives that provide the right motivational environment for learning, such as the Clinical Entrepreneur Training Programme, should be more widely supported. These initiatives need to be combined with organisational encouragement and support for innovations which benefit workforce learning.

9.1.2 Openness to collaboration

Multiple human minds working collaboratively can synthesise more powerfully.[162] This collective intelligence is more profound when synthesised across the boundaries of different disciplines,[163] for example, between the clinical workforce and computer scientists. This requires effective articulation and reformulation of knowledge, accurate estimation of group knowledge, effective listening, resolution of conflicts and the co-construction of new knowledge. The UK's current education system at the secondary and tertiary levels does not teach this effectively.[164]

Multi-disciplinary team learning will enable staff from across different disciplines to adopt new technologies and lead to sustainable change (E2). Exemplars already exist. The Perfect Patient Pathway Initiative aims to improve the lives of people with long-term conditions through technology by building a learning culture that focuses on collaboration with healthcare professionals and shared experience with other patients.

9.1.3 Effective co-design

Evidence suggests that the NHS can be resistant to co-design because it is difficult and time-consuming.[165] Demand pressures exacerbate this. However, incorporating patient participatory design into transformation projects will improve their chances of success and could strengthen patient-centered care. mHabitat provides a good example of the benefits of an NHS-hosted team specialising in co-design, engaging with all relevant stakeholders throughout the design process.[166]

9.1.4 Understanding human intelligence

We need to prepare the current and future healthcare workforce for the AI-enabled health system of the future by bringing humanity to the machine-patient interface. This includes focusing on the essential human skills that AI and computers cannot achieve, such as collaboration, leadership, reflection, compassion and empathy.[167] To deliver better healthcare and reduce misconceptions about the role of digital technologies, we need to have an understanding of what it means to be intelligent. The interwoven intelligence model, including academic, social and meta-intelligence, provides a very useful way of conceptualising intelligence to drive forward education in the 21st century.[164] Healthcare educators need to be aware of, and adopt, these evolving concepts of intelligence.

9.2 Methods of learning

A wide variety of learning methodologies should continue to be employed to support workforce learning through high-quality, co-created resources and interventions, including online, 'bite-sized', 'just-in-time' learning. Technology Enhanced Learning (TEL) can conjure up negative ideas of statutory and mandatory training with claims of educational benefits over traditional learning often going unsubstantiated. However, it can be useful in providing education at scale within the NHS. Blended learning, combining TEL with face-to-face experiences, can provide the essential combination of social, emotional and physical elements of learning. In time, collaborative virtual reality, for example, through holoportation, could potentially replicate the face-to-face element.

TEL has the ability to mature from a generic 'one-size-fits-all' model to a personalised and adaptive experience through data analysis of learners, their actions and their context using AI. The increasing ability to collect data about a wide range of learning activities, regardless of the tools or methods used to deliver them, enables decision-making by and for individual learners, educators and organisations. Additionally, digital technologies will make it possible to track and support life-long learning through records, independent of educational establishment, healthcare organisation or portal. Health Education England (HEE) is developing a digital learning platform that fills gaps in provision of learning across the NHS. **Figure 3** outlines an approach to developing AI for education and training. To complete the three essential activities (central rectangles), we need to create a virtuous cycle of training and engaging educators and developers in working together.

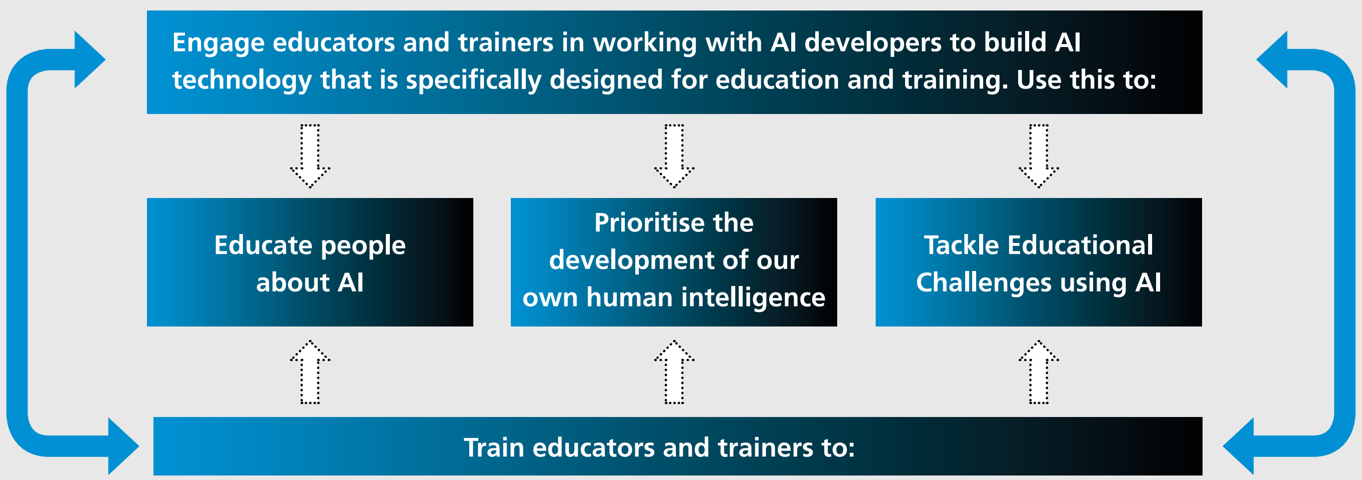


Figure 3: An intelligence approach to AI for education and training

9.3 Supporting educators

Educational leaders and educators, including quality improvement experts, are critical to driving a new learning culture. For these leaders to be truly transformational and deliver on their responsibilities, the NHS needs to support them to embrace culture change. This may include specific experiential learning within external companies who are engendering the culture the NHS is aiming to achieve. Given the pace of change, educators must be reflective in their approach, not only engaging in ongoing learning, but developing and adapting their educative practice through innovative ways to meet new and future challenges.

As champions of digital healthcare technologies, educators will be able to spot and nurture future champions and potential entrepreneurs for the NHS. Champions should be encouraged to share their knowledge and experience. Evidence highlights the benefits of networks within and across organisations that enable collaborative and guided learning.[169] The primary care 'digital nurse champions' is a good example.[170]

To ensure the timely upskilling of the NHS workforce, a greater investment in educators will be required (E3). Any member of the workforce could have the ability to become a potential educator, regardless of their role, level or qualifications. For example, a student nurse with expertise in certain aspects of digital healthcare technologies may prove an excellent educator. Similarly, new expertise in the NHS should be engaged in educating the workforce. For example, data scientists will be needed to educate the healthcare workforce in the utilisation of data as part of their wider role. This approach would also serve to promote collaboration between disciplines. NHS organisations will need to find mechanisms to identify and develop new educators within the workforce (E4).

9.4 Supporting the whole workforce

Digital literacy is a vital component for a learning workforce. It is defined by HEE as "those digital capabilities that fit someone for living, learning, working, participating and thriving in a digital society". **Figure 4** highlights the domains within the HEE Digital Capabilities Framework:

Figure 4: HEE Digital Capabilities Framework[171]

The capabilities listed in each of the sectors of **Figure 4** represent the skills, attitudes and behaviours which individuals require to be digitally competent and confident. They also support the development of a growth mindset and of the skills needed to enable co-design and creation. While release of time away from service provision is critical to the success of achieving widespread digital literacy, several additional challenges need to be overcome:

- reducing significant variance in current levels of digital literacy;[172, 173]
- raising workforce awareness of digital capabilities required;
- providing equitable access to support, learning and training with special efforts to engage and support the digitally unengaged or unconvinced;
- developing appropriate workforce skills and attitudes to empower patients and citizens to enhance their health and wellbeing through digital healthcare technologies.

Reflections on the Genomics Education Programme highlight that education has to evolve alongside the new technologies with frequent evaluations and flexible, adaptable and empowering curricula.[174] Practical, personalised approaches to enabling reframing of the knowledge and skills needed to acquire or expand digital capabilities must be developed. HEE should establish a new NHS Digital Education Programme to oversee the implementation of a national digital education strategy for both the generalist and the specialist workforce (E5). The digital literacy framework should be embedded into training programmes, career pathways and placements (E6).

Education providers should demonstrate the development of generic digital capabilities in their education and training provision. Professional and statutory regulatory bodies (PSRBs), practitioners and educators will have to come together to identify the knowledge, skills, professional attributes and behaviours needed for new graduates to work in an increasingly technologically enabled NHS (E7). For example, new Nursing and Midwifery Council standards highlight an innovative approach to workforce training with "more flexibility to harness new ways of working and embrace technology so they can equip nurses and midwifes of tomorrow".[175] All PSRBs have gone some way towards identifying the safe and effective utilisation of new technologies. They will need to ensure that their guidance is consistent and regularly updated, recognising the rate of change of genomics and digital technologies in the area of healthcare delivery.

Demonstrating appropriate levels of genomics and digital capability in relation to roles, the needs of patients and the needs of the service is required at significant touchpoints throughout careers. As new ways of working develop, some staff may move into areas of practice for which they did not originally train. Building digital capabilities into job descriptions, appraisals and CPD will allow for sufficiently dynamic and agile training, and support to keep pace with changes in technology, ensuring appropriately skilled staff. NHS organisations should ensure that current and new staff are supported to reach an appropriate level of digital literacy for their career stage (E8).

9.5 Supporting the specialist workforce

As the requirement for existing and new specialist roles expands, including clinical bioinformaticians, digital technologists, AI and robotics engineers, the NHS will need to develop career pathways to attract and retain talent (E9).

An essential requirement for staff working in specialised areas of healthcare is the provision of time and support to ensure their knowledge and skills are kept up to date through appropriate CPD. To meet the needs of specialised groups, CPD needs to be understood in a much wider context and be flexible and responsive. Development opportunities should be offered as tiered-level accredited training where appropriate. Approaches may include opportunistic out-of-programme experiences with industry,[176] cross-sector placements, staff exchanges and dynamic formal training curricula.[151] Training should be team-based and cross-disciplinary where appropriate (E10).

The accreditation of newer specialist groups needs to be strengthened, for example, working with national and international bodies such as the Faculty of Clinical Informatics and the Federation of Informatics Professionals who certificate informatics specialists (E11).

Senior specialist staff should also be provided with appropriate opportunities to develop their leadership and management abilities. Specialist digital healthcare technologies champions will be vital in supporting the wider workforce to adopt a change mindset and engender a learning culture in their institutions.

9.6 Educating the future workforce

Healthcare attracts some of the brightest and most committed people who want to make a real difference in peoples' lives. Consequently, supporting and fostering the desire of these future healthcare professionals to lead change in healthcare delivery is vital.

The requirement for flexibility and personalisation of learning should extend to the future workforce who should be able to move away from a one-size-fits-all approach. The change towards outcome-based education acknowledges that different individuals may learn at different rates, and so some students may demonstrate the required knowledge, skills and behaviours earlier than currently mandated. Hence, while some people could enter the workforce earlier, others may wish to spend time developing the skills needed to lead specific technological innovation.

9.6.1 Curricula

Healthcare knowledge is growing at such a rate that it is challenging to keep up to date. Access to mobile learning and machine learning means that there is a need to define what information students need to know, and what information they need to be aware of but not necessarily memorise. Similarly, the challenge for regulators, clinicians and educators is to identify what areas currently taught can be safely omitted from future programmes.

The routine use of information gathering related to patients' wellbeing will mean that students need to develop an understanding of health data provenance, curation, integration and governance, not only for the care of individual patients, but at a whole population level. Given the advances in genomics, the time allotted to this area in curricula is likely to need enhancing. Traditional clinical skills such as cardiac auscultation may be replaced by the use of handheld ultrasound devices, yet other skills such as communication, negotiation, collaboration and judgment will become even more important. The use of these skills in different contexts, such as online consultations, will need to be taught. It is possible that the concept of professionalism may need to be updated to take account of new ethical dilemmas that technological advances will bring. Assessment methods will also need to change to reflect modern concepts of where knowledge might reside – for example, using smart devices in examinations. Students will need to be able to use and explain AI, involving 'the machine as part of the team' to benefit patients (E12).

New technological developments are exciting and filled with promise, yet it is essential that empathy and compassion are not lost in a drive to embrace new ways of working. The adoption of digital healthcare technologies will increasingly emphasise the human qualities essential in clinician-patient relationships. The potential for more efficient ways of working should free up the clinician to spend more time with the patient, either in face-to-face meetings or remotely.

Opportunities for inter-professional problem-solving, for example, physiotherapists working with engineering students in the area of robotics, can enrich the learning experience and create the right skills for the future workforce. Education providers should offer opportunities for healthcare students to intercalate in areas such as engineering or computer science and new technologies as they emerge.

9.6.2 Selection

Healthcare students are currently selected on their academic credentials and a range of values aligned with the aims of the NHS. Educational providers need to ensure that prospective students have or gain additional skills, including: an appropriate level of digital literacy (E13); an understanding of the ethical challenges that the wider adoption of genomics and digital technologies will bring; a capacity for innovation; and an ability to address problems in an agile and flexible way.

In the future the NHS will need greater numbers of professionals with genomics, data science, computer science and engineering expertise to fill skills gaps in the NHS. This can be achieved through attracting graduates with these skills to begin a career in health, as well as offering opportunities for healthcare students to intercalate in these areas (E14).

> The transformational benefits that innovations in science and technology, such as artificial intelligence, can bring for patients and staff require a shift to a lifelong learning mindset throughout the NHS. Everyone must be supported to develop the mindset, skillset and behaviours that will empower the NHS workforce of the future."
>
> **Professor Rose Luckin**

9.7 Educational recommendations to support a digitally enabled health system The Review Board recommends:

9.7.1 Culture of learning

NHS organisations will need to develop an expansive learning environment and flexible ways of working that encourage a culture of innovation and learning. To do this:

- NHS organisations will need to: have a strong workplace learning infrastructure; cultivate a reputation for training and support; develop learning activities which are proactive rather than reactive; allow staff dedicated time for development and reflection on their learning outside of clinical duties. (E1)
- Each NHS organisation should adopt a multi-professional learning collaborative approach supporting staff to learn about genomics and digital technologies. (E2)

9.7.2 Supporting the educators

Delivering the education and requirements of the NHS workforce over the next five years will be challenging. In order to achieve this:

- The NHS and local organisations should support the development of a cadre of educators and trainers who can lead the educational programme to ensure timely upskilling of the NHS workforce. (E3)
- These organisations also need to put in place systems to identify and develop talented, inspiring new educators within the workforce. (E4)

9.7.3 Education and development of the whole workforce

Staff should have the opportunity to access information about genomics and digital technologies adopted by the NHS and develop the necessary skills. To achieve this, within five years:

- HEE should establish a new NHS Digital Education Programme to oversee the implementation of a national digital education strategy. The programme will complement the Genomics Education Programme. (E5)
- Employers must ensure that support for staff to develop and enhance digital literacy is built into training programmes, career pathways and placements. (E6)
- Professional, Statutory and Regulatory Bodies (PSRBs) and practitioners need to identify the knowledge, skills, professional attributes and behaviours needed for healthcare graduates to work in a technologically enabled service, and then work with educators to redesign the curricula for this purpose. (E7)
- Organisations responsible for employing and training must ensure that current and new staff are supported to reach an appropriate level of digital literacy for their career stage. (E8)

Specialist workforce and specialist teams will be working at the very forefront of their disciplines, often being early adopters of new technologies. Supporting these individuals and teams will be important for continued innovation. To support specialists and specialist teams in genomics, digital medicine, AI and robotics:

- For both existing and new roles addressing skills gaps in clinical bioinformatics, digital technologies, AI and robotics, the NHS should develop or expand both educational programmes (for example, the Higher Specialist Scientist Training) and attractive career pathways. (E9)
- The NHS should commission flexible and responsive training for specialist roles. This may include engaging with industrial learning organisations and developing placements, exchanges and secondments. (E10)
- The NHS should work with PSRBs and other bodies to introduce and strengthen accreditation of newer specialist groups. (E11)

9.7.4 Educating the future workforce

Within five years, we need to make sure that the education and training for future employees equips them to achieve their full potential as staff in the technology-enhanced NHS. To equip the future workforce:

- Education providers should ensure genomics, data analytics and AI are prominent in undergraduate curricula for healthcare professionals. Future healthcare professionals also need to understand the possibilities of digital healthcare technologies and the ethical and patient safety considerations. (E12)
- Education providers must ensure that students gain an appropriate level of digital literacy at the outset of their study for their prospective career pathway. (E13)
- Education providers should both offer opportunities for healthcare students to intercalate in areas such as engineering or computer science, and equally attract graduates in these areas to begin a career in health, to create and implement technological solutions that improve care and productivity in the NHS. (E14)

10.0 Conclusion

The Topol Review Board is pleased to submit this independent report with recommendations to the Secretary of State for Health and Social Care.

The Review has shown that opportunities afforded by the promise of genomics and digital technologies to prevent disease, predict the most efficacious treatments, deliver personalised care and invite active participation in wellbeing and support self-management must not be missed. The widespread adoption of these technologies has considerable potential to deliver service improvement, markedly improve productivity and the accuracy of diagnoses, and help to ensure a sustainable NHS. However, if the principle of universal healthcare is not to be eroded, but rather advanced by technology, it is important to ensure that everyone in the NHS is included.

As Dr Topol said when the Interim Report was published: "It really will be transformative that eventually… the patient will be truly at the centre."[178] Good healthcare relies not only on engaged and active patients, but also on "staff who know what they are doing, have the time to do it and treat [patients] with respect and compassion."[7] Motivation, a willingness to learn new behaviours, developing skills in collaboration and sharing knowledge are essential for NHS staff to be able to harness advances in technologies. Digital healthcare technologies offer the potential to reshape the patient-NHS relationship, empowering both staff and patients who are willing and able to become more actively engaged.

This Review highlights the potential scale of the change, the new roles likely to be required and the disciplines in which greater capacity is required. It identifies key areas in which specialised education and training are needed. To achieve transformational change through digital healthcare technologies requires a renewed focus on workforce development as a continuous and integrated element of working life, which empowers as well as educates.

Where should the focus of education and training be placed to maximise the opportunities and meet the challenges ahead? To reap the benefits, the NHS must focus on building a digitally ready workforce that is fully engaged and has the skills and confidence to adopt and adapt new technologies in practice and in context. The service needs leaders who can inspire and implement sustainable, systemic change. Boards require the expertise to make informed investment decisions, founded on real-world evidence of effectiveness, to drive improvement in a data-rich NHS. It is imperative that these improvements benefit every level of the NHS.

The greatest challenge is the culture shift in learning and innovation, with a willingness to embrace technology for system-wide improvement. An ambitious drive "towards the NHS becoming the world's largest learning organisation"[7] is the best way to respond to this challenge. Recognising that there will be a five-to-seven-year time lag to full adoption, there is now a window of opportunity in which to strengthen the infrastructure, upskill the workforce and catalyse the transformation. There is no time to waste.

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Board members, Expert Advisory Panel members, secretariat

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Appendix 2 – Glossary

A

AI – Artificial Intelligence

"Refers to a broad field of science encompassing not only computer science but also psychology, philosophy, linguistics and other areas. AI is concerned with getting computers to do tasks that would normally require human intelligence." (Stefan van Duin and Naser Bakshi, 2017)

www2.deloitte.com/se/sv/pages/technology/articles/part1-artificial-intelligence-defined.html

Augmented reality

"The addition of computer generated output, such as images or sound, to a person's view or experience of his or her physical surroundings by means of any of various electronic devices." (Taken from OED, 2018) (see also Virtual reality)

www.oed.com/view/

Automatic speech recognition technologies

"Concerned with models, algorithms and systems for automatically transcribing recorded speech into text." (Taken from teaching material in the School of Informatics at the University of Edinburgh, 2018)

www.inf.ed.ac.uk/teaching/courses/asr/

B

Bionanotechnology

"A branch of nanotechnology which uses biological starting materials, utilises biological design or fabrication principles or is applied in medicine or biotechnology." (Taken from Norwegian University for Science and Technology, 2015)

www.ntnu.edu/physics/bionano

C

CBT – cognitive behavioural therapy

"A talking therapy that can help you manage your problems by changing the way you think and behave." (Taken from NHS Choices, 2016)

www.nhs.uk/conditions/cognitive-behavioural-therapy-cbt/

CCIO – Chief Clinical Information Officer

"Provides leadership and management of ICT and information development activity to support the safe and efficient design, implementation and use of informatics solutions to deliver improvements in the quality and outcomes of care." (Taken from the Department of Health, n.d.)

www.digitalhealth.net/includes/images/Document_Library0365/Chief_Clinical_Information_Officer_job_description.pdf

Clinical bioinformatician

Works within multi-disciplinary teams to analyse and communicate genomic data today, and phenotypic data in the future, in the context of patient care[4].

COPD – chronic obstructive pulmonary disease

"The name of a group of lung conditions that cause breathing difficulties." (Taken from NHS Choices, 2016)

www.nhs.uk/conditions/chronic-obstructive-pulmonary-disease-copd/

D

Deep learning

Deep learning is a class of machine learning algorithms that:

- use a cascade of multiple layers of nonlinear processing units for feature extraction and transformation. Each successive layer uses the output from the previous layer as input;
- learn in supervised (eg classification) and/or unsupervised (eg clustering) modes;
- learn multiple levels of representations that correspond to different levels of abstraction; the levels form a hierarchy of concepts. (Adapted from Wikipedia, 2018)

en.wikipedia.org/wiki/Deep_learning

Digital therapeutics

"An intervention based on software," for example, apps or online interventions, "as the key ingredient", rather than drugs. Can also be described in terms of digital medicine and is sometimes referred to as "digiceuticals." (Taken from McKinsey, 2018 and Farr, 2017)

www.mckinsey.com/industries/pharmaceuticals-and-medical-products/our-insights/exploring-the-potential-of-digital-therapeutics

DNA

Deoxyribonucleic acid is the "the chemical that contains or 'encodes', genetic information. DNA is made up of four different chemical bases known as A (adenine), C (cytosine), G (guanine) and T (thymine)." (Taken from the Genomics Education Programme's Whole Genome Sequencing Glossary, n.d.)

Dynamic reporting

"A genome report that evolves to maintain relevance to the patient's individual clinical context over his/her life course." (Taken from Vassy et al, 2016)

www.ncbi.nlm.nih.gov/pmc/articles/PMC4348325/

G

Genomic biomarkers

"Measurable characteristics that reflect physiological, pharmacological or disease processes… They help deliver identification of disease genes, genomic signatures for therapeutic and disease risk scores and gene-environment (microbiome) profiles." (Taken from Guest et al, 2013 and the National Institute for Health Research, 2016)

www.guysandstthomasbrc.nihr.ac.uk/research/research-themes/genomic-medicine/

Genomic data

Information about the genome – "An organism's complete genetic material, including both genes that provide the instructions for producing proteins (2%) and the noncoding sequences (8%)." (Taken from the Genomics Education Programme's Whole Genome Sequencing Glossary, n.d.)

Genotyping

"The process of determining which genetic variants an individual possesses." (Taken from 23andMe, 2017)

customercare.23andme.com/hc/en-us/articles/202904600-What-is-the-difference-betweengenotyping-and-sequencing

H

HEE – Health Education England

The workforce and education body of the NHS in England.

Hospital at home schemes

"Enable patients to stay in their own homes while receiving extra care and attention from the 'hospital at home' team." (Taken from the Interim Report).

Human Factors expert

Someone who is knowledgeable about "enhancing clinical performance through an understanding of the effects of teamwork, tasks, equipment, workspace, culture and organisation on human behaviour and abilities and application of that knowledge in clinical settings." (Taken from NHS England, n.d.)

www.england.nhs.uk/wp-content/uploads/2013/11/nqb-hum-fact-concord.pdf

I

Immersive technologies

"A deeply engaging, multisensory, digital experience, which can be delivered using VR, AR, 360° video, mixed reality and other technologies. Formats vary." (Taken from Deloitte, 2018)

https://www2.deloitte.com/insights/us/en/focus/tech-trends/2018/immersive-technologies-digital-reality.html

M

Machine learning

Machine learning is a branch of artificial intelligence that allows computer systems to learn directly from examples, data and experience. Through enabling computers to perform specific tasks intelligently, machine learning systems can carry out complex processes by learning from data, rather than following pre-programmed rules.

royalsociety.org/~/media/policy/projects/machine-learning/publications/machine-learning-report.pdf

Modifiable risk factors

"Risk factors are conditions that increase your risk of developing a disease." If they are modifiable it means "you can take measures to change them". Examples include "smoking, obesity, high blood pressure, high cholesterol, excessive alcohol consumption and physical inactivity". (Taken from USCF Health, n.d. and Public Health England, 2018)

www.ucsfhealth.org/education/understanding_your_risk_for_heart_disease/

www.gov.uk/government/publications/using-the-nhs-health-check-programme-to-prevent-cvd

N

Natural language processing

"Takes an advanced neural network to parse human language. When an AI algorithm is trained to interpret human communication it is called natural language processing. This is useful for chat bots and translation services, but it is also represented at the cutting edge by AI assistants like Alexa and Siri." (Tristan Greene, 2017)

thenextweb.com/artificial-intelligence/2017/09/10/glossary-basic-artificial-intelligence-terms-concepts/

O

Online care pathway

Online care pathway, defined as a care pathway in which all or some elements of care are achieved online, is a complex intervention for the mutual decision-making and organisation of care processes for a well-defined group of patients during a well-defined period. (Adapted from http://e-p-a.org/care-pathways/)

P

Pathogen and microbiome sequencing

Method used to determine the exact sequence of pathogens – "disease causing organisms" and the human microbiome – "a community of trillions of bacteria, archaea, viruses and other microbes that are integral for human physiology, including vitamin production and helping provide an efficient immune response". (Taken from the Genomic Education Programme's Whole Genome Sequencing Glossary and Deloitte, 2017) (see also Sequencing).

blogs.deloitte.com/centerforhealthsolutions/12-medical-technology-innovations-likely-transform-health-care-2017/

Patient-generated data

"Health-related data created, recorded or gathered by or from patients (or family members or other caregivers) to help address a health concern." (Taken from HealthIT.gov, 2018)

www.healthit.gov/topic/scientific-initiatives/patient-generated-health-data

Phenotypic data

Information about the phenotype – "An organism's observable physical and biochemical characteristics (in humans, often the observed signs and symptoms of a condition); directly influenced by the genotype (genetic factors) and/or environment." (Taken from the Genomics Education Programme's Whole Genome Sequencing Glossary, n.d.).

S

Sequencing

A method used to determine the exact sequence of a certain length of DNA. (Taken from 23andME, 2017)

customercare.23andme.com/hc/en-us/articles/202904600-What-is-the-difference-betweengenotyping-and-sequencing-

Smart speakers

"A wireless and smart audio playback device that uses several types of connectivity for additional functions. Smart speakers have special features to enhance ease of use, connect to multiple types of audio scores and provide additional functionality." (Margaret Rouse, 2017).

whatis.techtarget.com/definition/smart-speaker

T

TEL – Technology Enhanced Learning

"Uses technology as part of the learning process. That use needs to be effective and appropriate in order to enhance the learning of healthcare professionals for the benefit of patients." (Taken from HEE, 2013).

hee.nhs.uk/our-work/technology-enhanced-learning

Telemedicine

"A subset of telehealth (the delivery of healthcare from a distance). It includes many subspecialties, such as telepaediatrics, telepsychiatry, teleradiology and telecardiology… using live videoconferencing systems." It can also include the transmission of data from one location to another. (Taken from National Leadership and Innovation Agency for Healthcare, n.d.)

www.wales.nhs.uk/technologymls/english/faq1.html

V

VR – Virtual reality

"A computer-generated simulation of a lifelike environment that can be interacted with in a seemingly real or physical way by a person, especially by means of a responsive hardware such as a visor with screen or gloves with sensors." (Taken from OED, 2018) (see also Augmented reality)

www.oed.com/view/Entry/328583?redirectedFrom=virtual+reality#eid

W

Wearables

"Designating or relating to a portable device (now especially one incorporating computer technology) that is designed to be worn on one's person." (Taken from OED, 2018 and Deloitte, 2014)

www.oed.com/view/Entry/226610?redirectedFrom=wearables#eid

www2.deloitte.com/uk/en/pages/technology/articles/wearables.html

Notes


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