Health Education England

The Topol Review

Preparing the healthcare workforce to deliver the digital future

Interim Report June 2018 - A Call For Evidence

Developing people for health and healthcare

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Contents

1.0 Preamble

In 2018 the NHS celebrates its 70th anniversary. While it is hard to predict the future, we know that genomics, digital medicine, artificial intelligence and robotics will have an enormous impact on patients and the workforce over the next two decades.

Digital technologies are transforming our ability to empower patients to participate actively in their own care, with a greater focus on well-being, to prevent diseases such as cancer and hypertension, to predict the most appropriate treatments and to personalise the management of long-term conditions (also known as chronic diseases), such as diabetes and asthma.

The Secretary of State for Health and Social Care, Mr Jeremy Hunt, has said[1]: "Every week we hear about exciting new developments surfacing in the NHS, which could help provide answers to some of our greatest challenges such as cancer or long-term conditions. These give us a glimpse of what the future of the whole NHS could be, which is why in the year of the NHS's 70th birthday I want to empower staff to offer patients modern healthcare more widely and more quickly."

Accordingly, the Secretary of State has commissioned this independent Technology Review as a key strand of the workforce development strategy, ensuring that the NHS is at the forefront of life-saving or life-changing care for decades to come.

Addressing questions that are integral to the future of the NHS, this Review has been asked to consider:

- How are technological (genomics, digital medicine, artificial intelligence (AI) and robotics) and other developments likely to change the roles and functions of clinical staff and their support in all professions over the next two decades?
- What are the implications of these changes for the skills required? For which professions or sub-specialisms are these likely to be particularly significant?
- What does this mean for the selection, curricula, education, training, development and lifelong learning of current and future NHS staff?

Additionally, the Review Board is clear that the future of medicine must primarily focus on the patient – and on a larger scale, the public. We must consider both what patients will require from healthcare professionals as new technological advances are deployed in the NHS, and how public and patient education can best be delivered, while respecting patient choice and acknowledging the diversity of the population.

Peel away the walls of the hospital and the doors of the GP surgery and you are left with the essence of the NHS: a human interaction between the patient and clinician. On a typical day, the NHS workforce interacts with over a million people. Each one of these interactions impacts on the life of an individual, their family, and often those providing informal care. Each contact reflects the professionalism, skills, compassion and empathy of the healthcare team.

With over 1.2 million staff in England, the NHS is the largest employer in Europe and one of the five largest employers in the world. This workforce performs over 300 different types of jobs for more than 1,000 separate employers in the public, private and voluntary sectors.

In a fast changing healthcare environment, with a growing and ageing population, the task of ensuring that the workforce has the skills, knowledge and time to care is essential to future proofing the NHS and its ability to meet patients' needs. There is little point investing in the latest technology if there is not a workforce with the right roles and skills to make full use of its potential to benefit patients.

This Review is building on existing strands of work in the NHS. The 100,000 Genomes Project, currently the largest national sequencing project in the world, was launched by NHS England and Genomics England in 2014. The Chief Medical Officer Dame Sally Davies's 2016 annual report 'Generation Genome' recognised there has been a "massive change in our ability to diagnose, treat and support patients with genetic diseases" and "that the UK has become the international leader in the field".

There have been a number of relevant reports recently published on the application of digital technologies to healthcare. The 2016 Wachter Review, 'Making IT Work', assessed the state of NHS IT services and made recommendations for what was needed to facilitate a

> This Interim Report is the beginning of the conversation.

digital healthcare future. It recommended that all Trusts should aim to achieve a high level of digital maturity within five years. It also recommended establishing a national programme to train Chief Clinical Information Officers (CCIOs).

Building on these foundations, this Review is proposing three key principles, which should govern the NHS's future workforce strategy:

- **Patients:** If willing and able to do so, will be empowered by new tools to become more actively involved and engaged in their care. The patient-generated data will be interpreted by algorithms enabling personalised self-management and self-care.
- **Evidence:** The introduction of any technology must be grounded in robust research evidence and a fit for purpose and ethical governance framework that patients, public and staff can all trust.
- **Gift of time:** Whenever possible, the adoption of technology should be used to give more time for care, creating an environment in which the patient-clinician relationship is enhanced.

This Review marks a historic opportunity for the NHS to learn from research, innovation and best practice in digital technologies for healthcare, while considering the implications for the education and training of its workforce. It is essential that all healthcare professionals are ready for the digital future, a future which puts care at the forefront of healthcare.

This Interim Report is the beginning of the conversation. Evidence and comments are being sought from any organisation or individual with an interest in workforce education and development, with a view to informing the Final Report.

2.0 Approach

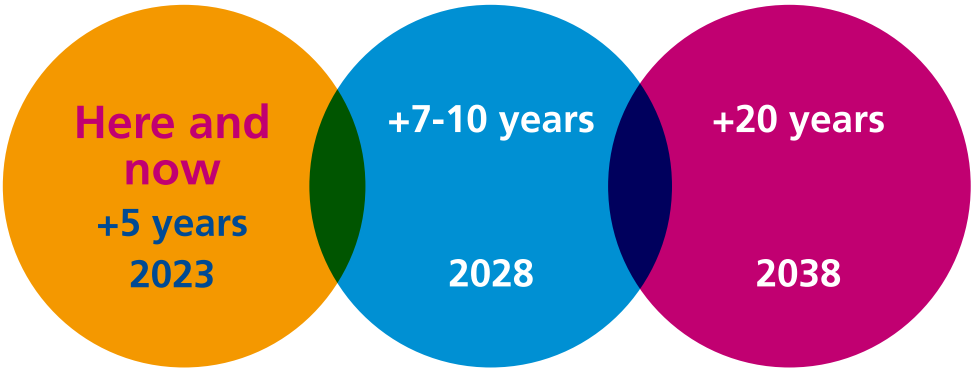
Dr Eric Topol is leading the Review and has formed a Review Board of leading experts in genomics, digital medicine, AI and robotics. Health Education England (HEE) is facilitating the Review.

The Review Board is working through three Expert Advisory Panels. This is the first time that such an array of subject matter experts – clinicians, public health experts, economists, educationalists, ethicists, engineers, physical scientists, lay members of HEE's Patient Advisory Forum and researchers – have been assembled to focus on education and workforce development.

The work of the Review is taking a phased approach, with the Expert Advisory Panels gathering evidence from diverse sources. The first phase has involved research and engaging with individuals and national networks to gather knowledge and evidence, and identify the key themes.

This Interim Report launches a wider discovery phase through summer 2018 to inform the Review, with an open call for evidence, followed by a series of workshops with key stakeholders, including representatives from patient groups and the public.

The Panels are taking into account realistic timeframes for making changes in workforce development, education programmes and curricula. The Review will look at near-term programmes (the next five years), plausible medium-term changes (the next decade) and the potential for long-term developments (on a 20 year timescale). The focus of the Interim Report, however, is on the here and now.



The challenge for the Review is to explore the options available on these different timescales systematically, and to use the evidence it gathers to offer conclusions in the Final Report on what this means for the education and training of the workforce.

The Final Report will be submitted to the Secretary of State for Health and Social Care in December 2018. Wider engagement on the findings is planned from January 2019.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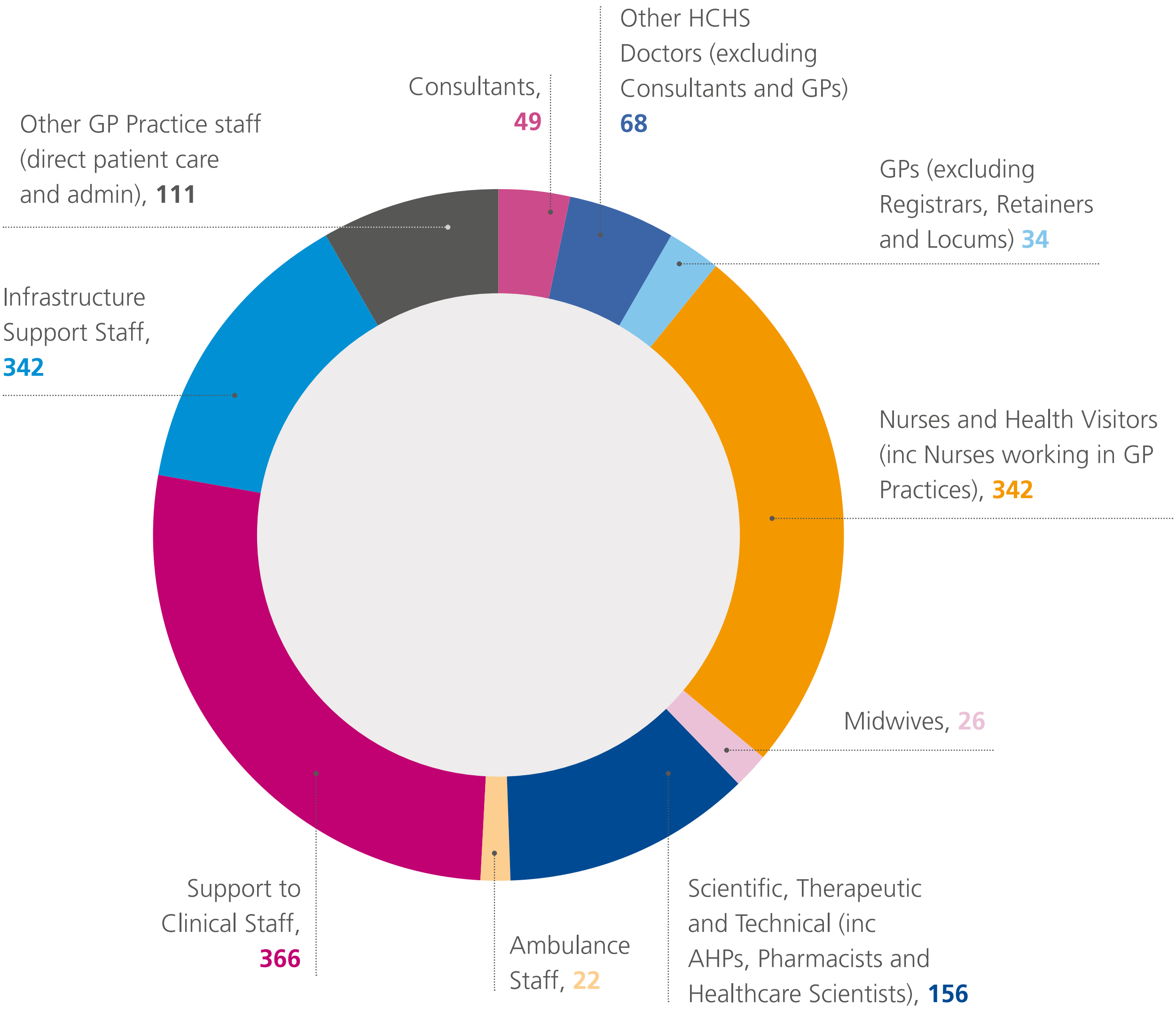
3.0 Workforce profile

The current NHS workforce in England is comprised of the following high-level groupings

Figure 1: Numbers of staff in Hospital and Community Health Services (HCHS) and in General and General and Personal Medical Services by group (000s)



(Source: NHS Digital)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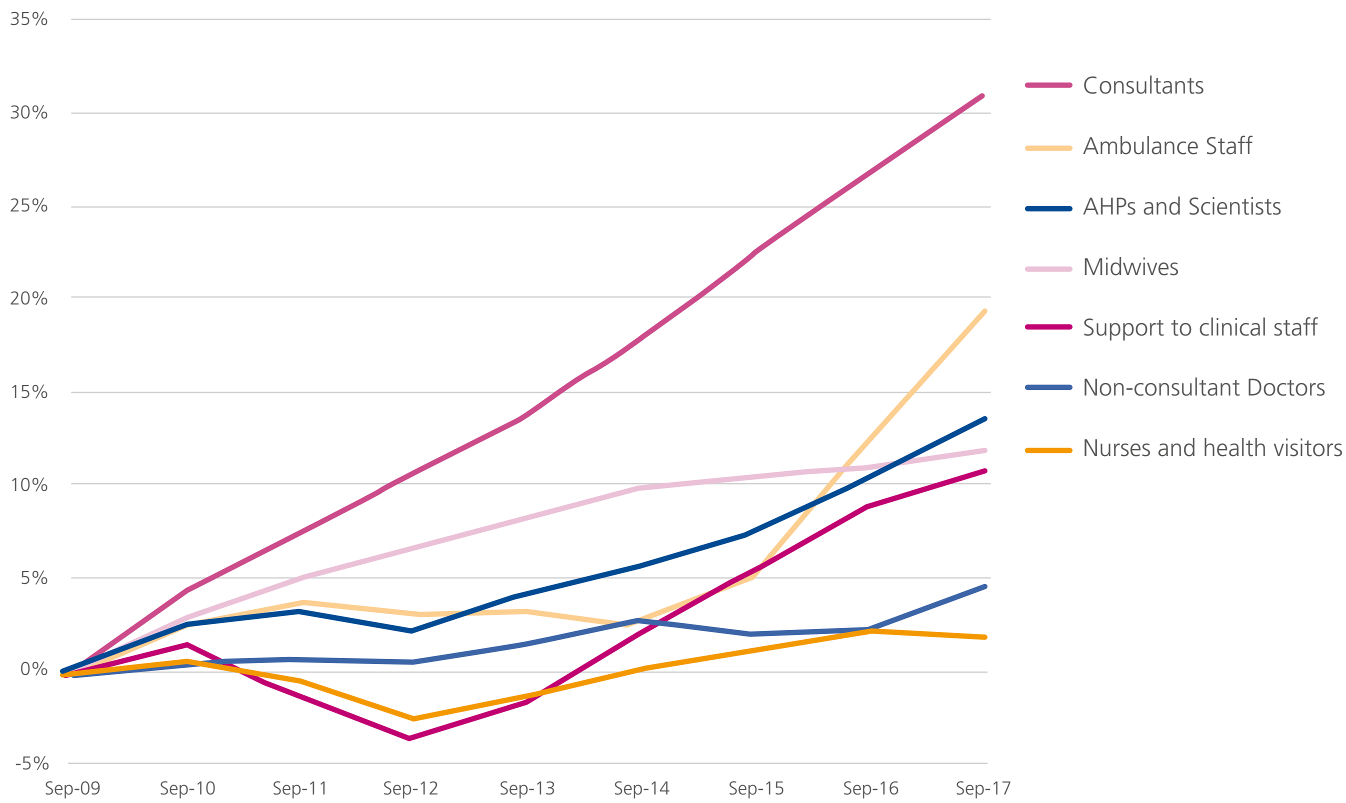
We are one profession

Over the last eight years there has been differential growth in different staff groups

Figure 2: Percentage increase in Hospital and Community Health Service (HCHS) staff 2009-2017



(Source: NHS Digital)

The NHS employs more staff now than at any other time in its 70 year history. Whilst the workforce has grown, it has not kept up with ever increasing demand. The NHS is treating a growing and ageing population that has grown by 2.1 million (4%) over the last five years. HEE forecasts that if we fail to reduce demand and increase productivity, then we will require at least 190,000 more staff by 2027 (Fig. 3). Maintaining the current rate of growth will provide an additional supply of 72,000.

This Review will help forecast, in its Final Report, whether incorporating the new technologies will have an impact on the projections for the expanded workforce, with different types of staff likely to be needed in different numbers, as staff roles change or new roles emerge.

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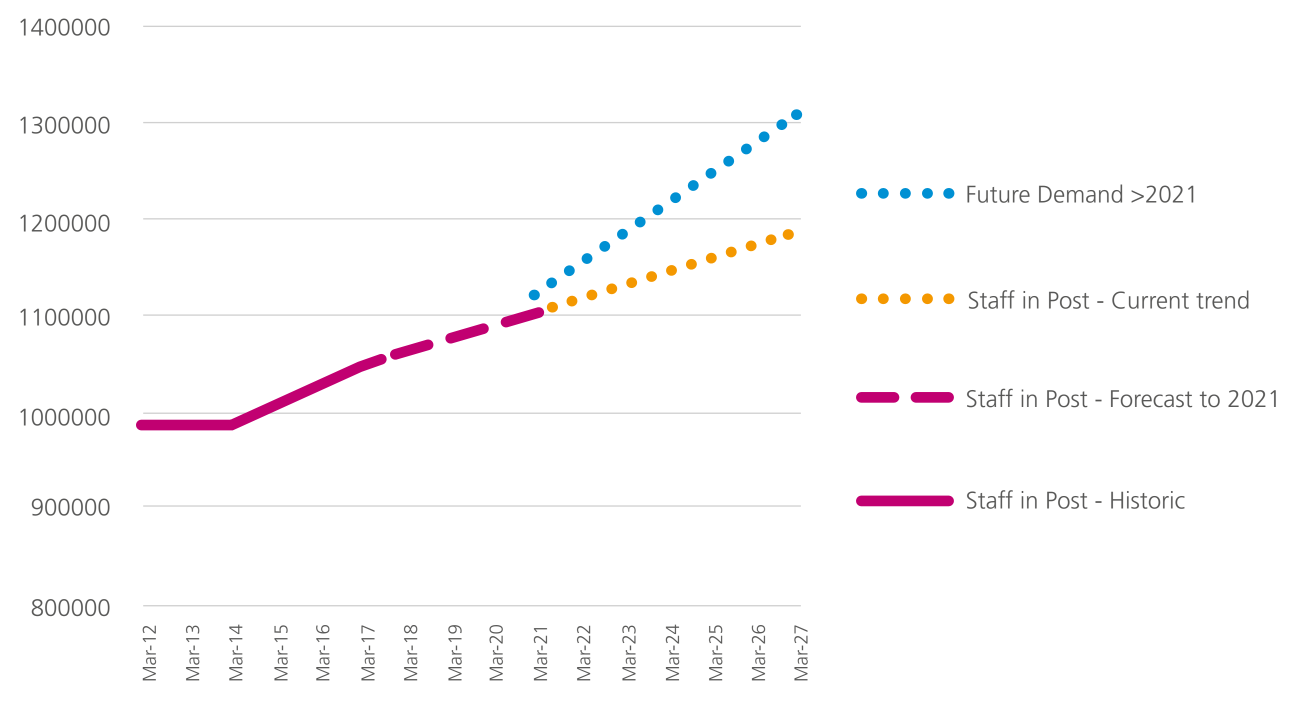
Figure 3: Recent Projection for Future Demand for Staff - Beyond 2021/22



4.0 Educating the healthcare workforce

The successful integration of any new technology or system into the workplace requires a highly engaged and appropriately trained workforce. There are known barriers to embracing technological changes in healthcare. These include lack of trust in new technologies, the precedent of poor previous experience with electronic health records, fear of the pace of change and the feeling of being unprepared to engage with new systems.

The education and training of the existing workforce, along with the preparation of an appropriate pipeline of talented future staff, will be key to the success of any programme of change designed to empower staff to take advantage of the advances in technology to improve service delivery. HEE has already launched a Genomic Education Programme, initially with a £20million pound investment by the Department of Health, which includes a multi-professional MSc in Genomic Medicine currently commissioned in seven Higher Education Institutes.

The NHS Digital Academy has also been set up as a virtual organisation with a brief to develop a new generation of excellent digital leaders[2]. It will train 300 Chief Clinical Information Officers in the next three years.

The continued professional development of the existing workforce will need to be different for those 'specialist' members of staff who will be intimately involved in using new technology compared to the 'light touch' education required by other members of staff who will probably only need to know general principles. For the latter, HEE has already started Building the Digital Ready Workforce and has a well-established Technology Enhanced Learning programme.

Additionally, it will also be crucial to address the needs of returners if we are to retain these individuals. At the same time, by working with schools and universities, we need to ensure that the next generation of clinicians have the digital literacy and patient engagement skills which the NHS of the future will require.

Genomics in primary care

Healthcare professionals in primary care will need to be educated and trained in genomics for a variety of purposes. For example, they will increasingly need to incorporate polygenic risk scores in assessing risk of various chronic diseases and implementing primary prevention.

- Take genetic variation into account when making therapeutic choices.
- Consider the implication of genetic diagnosis for counselling and screening of the extended family.
- Have a sufficient knowledge of genomics to have a sensible dialogue with patients across a spectrum of questions.
- Know when, how and where to refer patients to for specialist advice.

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4.1 Requirements of a future workforce

The knowledge and skills which a future workforce will require in an era of technological advancement can be considered under the following headings:

- What needs to be retained?
- What new things are needed?
- What needs to be enhanced?
- What could be devolved to external sources?

With the advent of cognitive computing, it will be important to identify what knowledge clinicians need to have to provide up to date, safe healthcare. And where should that knowledge reside – in their heads, on their mobile device or from the 'machine as part of the team'?

The use of small mobile ultrasound devices means that some traditional clinical skills, such as listening to heart and lung sounds, may be superseded. However, skills and attributes such as communication, compassion, empathy, and caring will retain a central role for clinicians. Furthermore, the improved workflow and efficiency of new technologies affords the opportunity for not just retaining, but enhancing and giving higher priority to the patient-doctor relationship. Creativity, innovation, enterprise and an ability to embrace and lead change will need to be fostered.

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New areas of knowledge and skills will be required... as well as a major increase in digital literacy.

New areas of knowledge and skills will be required, such as an understanding of genomics or AI algorithms and the ability to analyse and understand the implications of big datasets in the provision of future healthcare services, as well as a major increase in digital literacy.

Given the history of failure of previous technological systems within the NHS, it will be important to engage the hearts and minds of the workforce who, given the intensity of the present workload, may feel beleaguered and cynical when asked to adopt and trust new technology. Consideration needs to be given to involving clinicians in user-centred design and co-creation of new ways of working.

The advantages of adopting new ways of working over existing systems must be made clear and sufficient time for training and re-training will need to be incorporated into normal working hours. Delivering the education and training for the NHS workforce in England will require a significant investment in 'educating the educators'.

As well as the upskilling of existing clinicians, consideration should also be given to the desirability of developing new professional groups such as clinical data scientists, medical software engineers and digital medicine specialists. New technologies and the emergence of increasing amounts of patient data will bring with them the need for increased training in ethics and data governance. Delivering the positive impact that these new technologies could have on the NHS will require digital leadership across the health and social care system, with a willingness to embrace new technologies.

4.2 Methods of education and training

Technology will be increasingly useful in providing education and training at scale. The development of online courses, podcasts and Massive Open Online Courses (MOOCs) or Small Private Online Courses (SPOCs) is likely to become important to reinforce or supplement face-to-face teaching. The use of augmented reality/virtual reality and immersive environments will also have a role, especially in those areas which are difficult to cover in the workplace and as their cost becomes more affordable.

In summary, the potential to reshape and improve healthcare using new technologies is huge, but without a highly trained workforce, confident and competent to use these new systems, in partnership with the patient and the carer community, their full impact is unlikely to be realised.

5.0 Ethics

Whilst technological developments promise very significant benefits to improve healthcare, many rely critically on the ability to collect, store, access and share health related data, including data gathered via pervasive surveillance techniques (through continuous monitoring and tracking) that many consider highly intrusive.

Within constitutional democratic societies, surveillance, even for laudable purposes, is not acceptable unless it is undertaken in ways that are consistent with the fundamental rights to privacy and data protection.

Without transparent, resilient, robust and legally enforceable data governance structures[3], policies and practices that the British public regard as ethical, rights-respecting and trustworthy, the promised benefits of data-driven technological innovations in healthcare and medicine will not be realised.

At the same time, the NHS is founded on a commitment to equal and equitable access to healthcare for all UK citizens. However, the health and well-being gap was highlighted in NHS England's Five Year Forward View as one overarching reason why the NHS needs to change.

Although access to digital technologies has the potential to improve and streamline patient care within the NHS, there is a real risk that existing inequalities may be exacerbated unless consideration is given as to how technological innovations affect equality and equity in healthcare.

These ethical concerns are shared in the Nuffield Council of Bioethics' Briefing Note on artificial intelligence in healthcare and research. It is very important to focus on how equal access to advanced healthcare can be assured. Indeed, the new technologies could either improve or worsen health inequities; the objective should always be to maximise the positive impact.

6.0 Health economics

The introduction of new technological developments in genomics, digital medicine, artificial intelligence and robotics in healthcare has the objective of improving the care of patients either directly or indirectly by using health service resources more productively.

However, efficiency alone is not sufficient and may be traded off against effectiveness and equity. This has implications for which technologies are developed and how they are used. A technology seeking to maximise efficiency may look very different to a technology addressing the same issue but also seeking to improve equity.

The adoption of a new technology in one part of a health service may have ramifications for care provided in other parts of the service. It may also spill over into effects beyond healthcare. For example, a new genomic test that characterises the underlying causes of bone development abnormalities in children may directly allow earlier treatment and therefore alter the subsequent need for orthopaedic surgery on the children affected.

An indirect impact on the health service is that the introduction of this test may reduce the ability to provide certain types of surgery other than in specialised centres. A further indirect impact is that it may reduce the need for long-term social care support as children have less disability.

In this case, the spillovers are positive, but in other cases it is possible that they might be negative. For example, a new technology to treat stroke may increase the number of stroke survivors but still leave these people with considerable disability. This would in turn increase the need for rehabilitation services and social care services, as continuing care is typically provided in the community.

There would also be a wider impact on patients and families, because an important component of care for someone who has had a stroke is that informally provided by friends and family. These informal care costs will be disproportionately more important to those who are less well off.

"The adoption of a new technology in one part of a health service may have ramifications for care provided in other parts of the service.

A narrow consideration of the costs and benefits of adopting a technology that only takes the perspective of an individual provider for the NHS will miss these spillover effects. This runs the risk that any policy based upon a narrow perspective will not be an efficient use of society's resources and may increase inequalities within society.

The value of any new technology is also dependent upon the ease in which that technology can be implemented into practice. A technology that can be readily slotted into care and practice may be able to realise productivity improvements relatively quickly and so improve patient outcomes, efficiency and reduce inequalities. The more disruptive a technology, then the longer it may achieve these benefits in practice. It was only in the 1980s that IT was used in the majority of industries and it took time to learn how to use the technology to its best advantage.

Similar issues may be expected within health care. For example, if a new test is better able to determine the risk of recurrence or progression for those who have been treated for cancer, this could provide some immediate improvements in the care of patients but without fully understanding how the technology is best used, its full benefits may not be immediately realised.

7.0 Themes

Expert Panels have been convened to provide expert evidence on the following three themes: (i) genomics; (ii) digital medicine; (iii) AI and robotics.

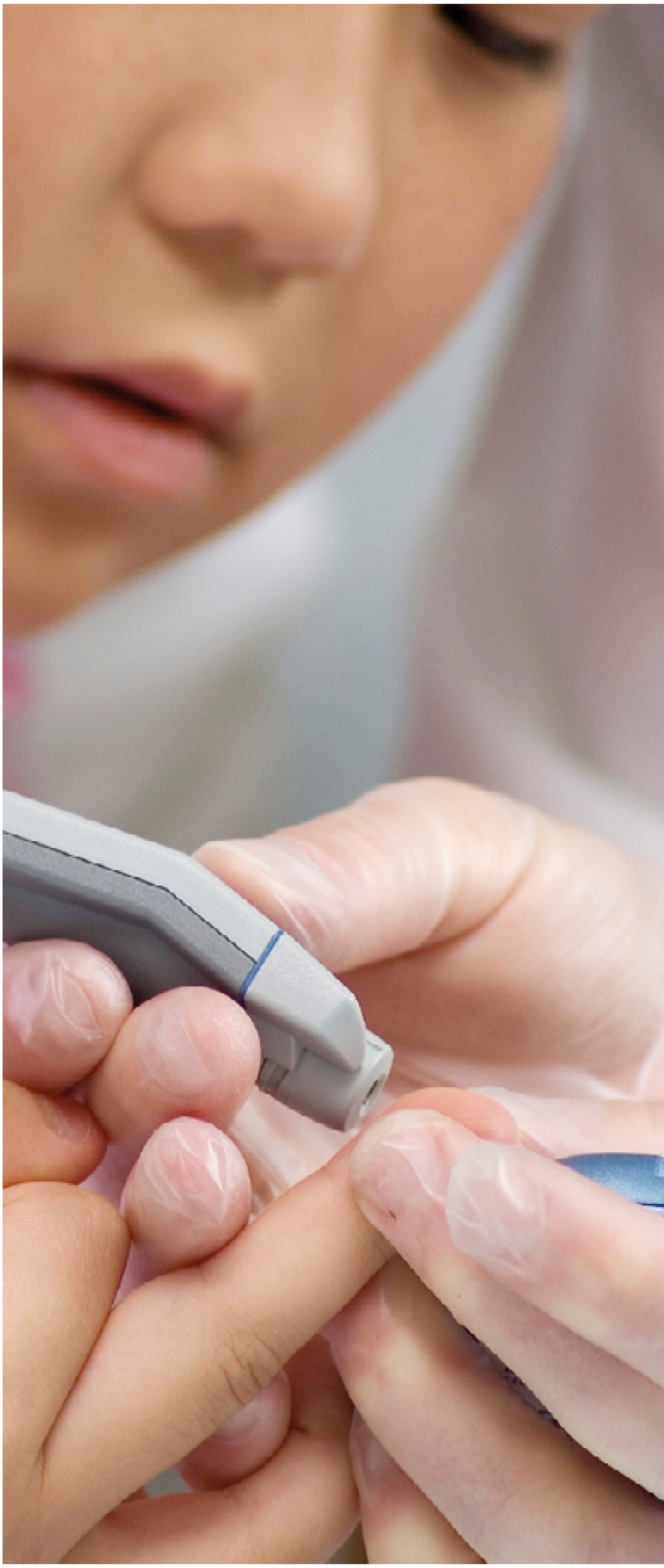
Their early findings are summarised in the sections below. Of the technologies considered, genomics is the most advanced, in terms of research evidence, implementation, and workforce development, with a new MSc programme and newly created NHS roles.

This is followed by digital medicine, which is rapidly advancing with the spread of smartphones and computer tablets, although uptake remains uneven. More research is needed to evaluate clinical pathways that take advantage of digital technologies within optimised health systems. Further training will inevitably be required if the workforce is to benefit fully from digital medicine.

At the other end of the innovation pipeline, we are only just beginning to discover the potential for AI, in particular machine learning, to personalise care, improve patient outcomes and reduce the workload of healthcare professionals.

The real power of these technologies is likely to lie at their intersection. The fusion of genomics, digital medicine (including patient generated data) and AI, could deliver a more holistic approach to personalised healthcare and disease prevention. Although the type and amount of data will vary and change at very different rates (from once in a lifetime for genetic data to once a second for some types of wearable data), AI algorithms will become increasingly important to extract clinically useful information from such disparate data.

The impact of this integration will also vary from one medical specialty to another. In oncology, for example, the integration of multi-omics with clinical phenotypes to analyse data will enable the prediction of a patient's response to new cancer therapies.



8.0 Theme 1: Genomics

The UK is a world leader in genomic research and medicine and well placed to remain in the vanguard of future developments. Over the next 20 years, there will be major advances in the use of genomics across diverse areas of medicine.

For example, rapid sequencing first approaches in sick newborns – along with children or even adults – with unknown but serious conditions will reduce the 'diagnostic odyssey' – the long delays and marked expense of traditional medical evaluation. Genomics will revolutionise multiple aspects of cancer care, from prediction through to screening, diagnosis, treatment and post-treatment surveillance. Preventative strategies for the common diseases of ageing will be bolstered and made more precise 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. New forms of treatment, especially for inherited diseases, will emerge based on genome editing and cellular replacement.

Substantial progress in service transformation to incorporate genomic medicine has already occurred throughout the NHS. In England, preparation for the implementation of genomic medicine has been led by NHS England and Genomics England, through the 100,000 Genomes Project[4,5] and the establishment of Genomic Medicine Centres. In parallel, the HEE Genomics Education Programme has been responsible for preparing the NHS workforce to deliver genomic medicine through knowledge, skills and experience. There are a growing number of examples where patient management has been transformed through genomics.

8.1 The citizen and the patient

Genomic medicine is likely to impact citizens in many different ways and at different stages of their life-course. If they are to become more active contributors to their health and care, they must be supported to develop their understanding of genomics. This will require easy access to relevant knowledge resources, as well as a 'socialisation' of genomics that allows them and their relatives to interpret the personal implications of findings arising from genetic and genomic information.

Citizens will need to be supported to engage with decisions around risk, ethics, privacy, insurance, employment and fertility. Genomics needs to be factored into school and workplace education, with parallel approaches to inform the adult population.

Individual patient decisions regarding the use of sensitive data for clinical and research purposes must be based on transparent discussion about the costs and benefits of data sharing, and updating of the social contract underpinning delivery of a national health service. This will involve clear articulation of the benefits in terms of better, more tailored care, more accessible and effective interactions with the health system, and the fostering of further advances through research.

Patients and carers must have confidence that there is adequate regulatory protection in the public and the private (including direct to consumer) sectors, with respect to data misuse and unsupported claims.

These advances will require a more equitable relationship between the patient and their clinician, recognising that wider access to information and personal empowerment will result in citizens who are ever more informed about their health and any condition which they may have, and who also expect shared decision making.

8.2 Healthcare professionals

We anticipate a gradual, but substantial, reconfiguration of clinical roles to meet the new challenges associated with the introduction of complex, evolving genomic technologies. The pace of change will differ by speciality and by individual medical practice, but will ultimately impact on all healthcare professionals.

Individual workforce training needs will depend less on traditional role demarcations, and more on specific responsibilities related to 'real-world' implementation. For example, for a given genetic test, members of the workforce will be variously contributing to commissioning, gaining consent (of patients), ordering, genetic test data generation, interpretation, patient communication and family support. This will require training that supports their specific activities. This will be associated with acceleration of the shift towards multi-disciplinary working and a change in many professional roles.

Widespread introduction of genomic technologies within the NHS will require a combination of distributed ('mainstreaming') and centralised procedures (e.g. related to ordering and interpretation of a genetic test). Healthcare professionals of all kinds will increasingly be involved in aspects of care previously devolved to more specialised colleagues, such as those related to 'routine' genomics (e.g. pharmacogenetics, and risk prediction for common diseases).

Given the evolution of knowledge and the relevance of genetic information to the health status of relatives, clinical responsibility will extend beyond the index consultation. This includes 'dynamic reporting', supporting re-contact with patients when updates in knowledge mandate revision of previous clinical advice. This long-term duty of care extends beyond the index cases to their wider families.

Counselling[6] and broader support mechanisms will require expansion to address the complex task of conveying risk and other probabilistic information to patients and their families.

Undergraduate and postgraduate curricula for all healthcare professionals must include genomics and its relevance. Education and training should also be rolled out to existing healthcare professionals as part of a system for life-long learning, accreditation, and retraining. Given the rapid pace of technical development and knowledge accumulation, healthcare professionals will – in addition to generic training and tailored accreditation schemes – need access to real time resources to support dynamic, up to date, interpretation and decision making.

Clinical education should emphasise, not the burden of acquiring additional knowledge, but opportunities for improvements in the overall quality, productivity and equity of care.

Genetic Diabetes Nurse

The Genetic Diabetes Nurse (GDN) role has been developed to support the integration of genomic testing into diabetes care. GDNs are experienced diabetes specialist nurses who raise awareness, understanding and recognition of monogenic forms of diabetes. An accurate genetic diagnosis is essential to identify those patients who may benefit from treatment tailored to their genetic subtype. GDNs work as a national network with training provided by an expert multi-disciplinary team of clinicians, nurses and scientists based in Exeter. The GDNs liaise with local healthcare teams to advise about genomic tests, help co-ordinate genetic testing for family members and support patients through treatment changes.

Clinical Bioinformatician

A Clinical Bioinformatician works within multi-disciplinary teams to understand the needs of the services and communicate genomic data today, and phenotypic data in the future, in the context of patient care. Clinical Bioinformaticians are able to evaluate, validate and understand the limitations of available tools and choose those most appropriate to meet the needs of the clinical service, as well as analyse data using appropriate software tools. Bioinformatics training in the NHS will be an evolving programme of workforce development and transformation, starting with genomics and broadening out to include phenotypic information, including patient-generated data.

8.3 Health system

Reconfiguration of the health system is essential if genomic medicine is to be implemented in ways that ensure patient safety and data privacy, improve equity and productivity, reduce unacceptable variation in quality and outcomes, and enable sustainability.

This will require infrastructural developments that capitalise upon existing efforts, for example, to integrate clinical genetics services nationally, to extend genomic multi-disciplinary teams, and to develop a national genomic laboratory network underpinned by the genomic testing directory. There will need to be substantial revision of service provision to ensure that the NHS meets its obligations regarding the follow up and management of significant findings in the relatives of index cases.

Genomic medicine will necessitate development of new specialisms (and/or substantial expansion of existing workforce) in diverse areas including genomic counselling, bioinformatics, computing, data sciences, health economics and commissioning. This will require appropriate training, and robust structures for career progression and staff retention. It will involve a marked expansion of opportunities for the re-training of existing staff, recognising that workforce requirements for some specialised roles will decline.

The Genomics Education Programme will continue to play a key role in developing an educational framework for the workforce and undertaking workforce planning and modelling.

There need to be parallel mechanisms for supporting methodological and mechanistic research in the academic sector which uses NHS data to advance translational objectives. Above all, 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 of care delivered.

Genomics in Cardiology

Cardiologists and other health care professionals in cardiovascular medicine will encounter patients and families who may have an inherited cardiac condition. They therefore need to be trained and educated about genomics, when it could be relevant, know when and how to refer to a Specialist Inherited Cardiac Conditions service and be aware of the importance of taking a family history. The ability to tailor cardiac drug treatment to an individual's genetics is rapidly increasing, and so education and training for healthcare professionals will need to be agile and adapt to this rapidly progressing field.

9.0 Theme 2: Digital medicine

The fast changing pace of digital medicine is already having a positive impact on the NHS, although the rate of take-up and benefits are unevenly distributed amongst the population.

In this report, digital medicine is defined as digital technologies and products that directly impact diagnosis, prevention, monitoring and treatment of a disease, condition or syndrome. This includes telemedicine, wearables, digital diagnostic tests, bionanotechnology, digital therapeutics and immersive technologies such as virtual and augmented reality.

Today, an estimated 89% of UK adults have used the internet in the previous three months[7] and use among women aged 75 and over has almost trebled since 2011. NHS England, in May 2018, estimates that 24% of patients in England (13.9 million people) are now registered for online services with their family doctor to book appointments, order repeat prescriptions and view their records – saving time for themselves and busy GP practices. Half of all adults access health information online; each day, there are approximately 1.6 million online searches for health information on NHS Choices (82% via search engines and 75% of visits on a mobile or tablet device). NHS England also estimates that 60% of the people who use the internet to check a condition do not then go on to access a frontline service.

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9.1 The patient

Digital medicine is increasingly empowering patients to manage their own health and well-being, and this will naturally transform the traditional patient-clinician relationship. There is a growing acceptance of the use of smartphones and wearables to track vital signs, such as heart rate and abnormal rhythms, blood glucose and blood pressure[8]. Amongst those who use digital technologies to manage their health, use of wearables went up from 22% to 31% between 2016 and 2018. Launched in April 2017, the NHS Apps Library provides digital tools for patients with a range of conditions, from diabetes, chronic obstructive pulmonary disease and cancer to depression. There are currently 47 'trusted and assessed' apps available in the Library (https://apps.beta.nhs.uk).

Cognitive Behavioural Therapy (CBT) is increasingly being delivered digitally, for example for the management of sleep disorders. Activist patients are co-developing new digital technologies to meet their needs, such as the #Wearenotwaiting movement for diabetes.

To increase the adoption of digital health technologies, public health campaigns should include education on modifiable risk factors and training on how such technologies can be used to prevent common conditions such as obesity and hypertension. There is a need for investment in national digital literacy public health campaigns to educate everyone, from children in primary schools, to young adults and the elderly. For those without direct access to the technologies, digital health learning tools should be made accessible in schools, public libraries and GP surgeries. The adoption of digital medicine must not have the unintended consequence of increasing health inequalities.

With this in mind, NHS Digital has recently released for commissioners and designers of digital health technologies a 'Digital inclusion guide for health and social care' (https://digital.nhs.uk/about-nhs-digital/our-work/digital-inclusion).

9.2 Healthcare professionals

The Wachter Review highlighted the need for digital leadership in the NHS, and this year the first national NHS Chief Clinical Information Officer was appointed. To deliver the benefits of digital medicine throughout the NHS, healthcare professionals will need to learn about data management, data privacy, data quality, ethics and regulation. They will have to be trained in how to interpret patient-generated data (including data from wearables acquired over several weeks or months) alongside traditional health data such as X-rays and blood tests.

Emerging technologies, including smartphone-connected diagnostic tests, will enable earlier diagnosis of disease, more personalised/stratified treatments, and could also reduce the unnecessary prescribing of antibiotics. Doctors will need to learn how to prescribe digital therapeutics, for example evidence based apps available from the NHS Apps library as an alternative to drugs. In future, interventions will increasingly focus on disease prevention, health and well-being.

Online consultations[9] and video calls, as an enhancement of telephone triage, will gradually become accepted within primary care and potentially secondary care, for example in Accident and Emergency. The number of online consultations may eventually supersede the number of face-to-face consultations, necessitating new training in remote patient management. Benefits will include increased productivity, both for patients who will not need to take time off work to visit the clinic, and for clinicians, with more time becoming available for them to care for more complex, serious cases through face-to-face appointments.

The deployment of digital technologies within the NHS should be user centred and have as one of its main objectives the reduction of the administrative burden on healthcare professionals. For example, automatic speech recognition technologies, also known as 'smart speakers'[10], and other 'machines in the team', should allow doctors and nurses to spend less time entering information using their computer keyboards during face-to-face consultations, and so free them to focus and connect more with the patient.

Mechanisms by which the existing healthcare workforce could be given dedicated time to learn how digital technologies can enhance their practice of medicine should be introduced, for example through immersive virtual reality for trainee doctors prior to new rotations, mentoring apps and agile MOOCs for lifelong learning.

Diabetes specialist midwives

Gestational diabetes affects between five and 16% of all pregnancies in the UK. It is important for the health of the mother and baby that glucose control is maintained, but as a result of the dynamic physiology of pregnancy, it is difficult to predict how blood glucose levels will respond. The GDm-HealthTM management system, developed by researchers from Oxford University and clinicians from Oxford University Hospitals NHS Foundation Trust, provides real-time management of gestational diabetes and reduces the number of clinic visits. The system was designed with extensive input from both patients and clinicians. It comprises a smartphone app for the patient and a secure website, with optimised data presentation and alerting algorithms for healthcare professionals.

Local care pathways have been changed to allow a reduction in unnecessary clinic visits. Similarly, the job plans for midwifes are being modified to accommodate new ways of working with remote management of pregnant women.

9.3 Health system

The benefits of digital medicine will only be realised at scale, within a fit for purpose, trusted NHS governance framework. More interdisciplinary research, with large scale test beds, is needed to evaluate the impact of the new technologies, and their implications for data governance.

Today, the delivery of care largely centres around the attendance of patients in clinics for face-to-face consultations. In future, remote delivery of care to patients in their homes will become more prevalent via telemedicine. The healthcare workforce and patients will need to be trained in how to use telemedicine in new online care pathways to diagnose, monitor, educate and treat patients.

More acute care will also be possible through the expansion of 'hospital at home' schemes, which enable patients to stay in their own homes whilst receiving extra care and attention from the multidisciplinary hospital at home team. These schemes are designed to give patients extra support at home using technology, to ensure that they are not admitted to hospital or that their admission is as short as possible. The aim is to reduce the pressure on emergency departments and manage demand for acute care.

The vision should be to deliver high-quality personalised care regardless of location (home, care home, pharmacy, community hospital or acute hospital). This will be enabled by appropriate patient monitoring technology (a combination of wearables, smartphones and their accessories), supported by the deployment of community nurses, and paramedics for rapid response when needed.

New professional groups will need to be grown within the NHS (e.g. behavioural psychologists, human factors experts, medical virtualists[11]) to extract maximum benefit both for patients and for the workforce. New roles and career pathways will emerge for clinical bioinformaticians and healthcare data specialists with an interest in developing machine learning algorithms to analyse NHS datasets to support public health research, for example to predict influenza epidemics.

Support Hope and Recovery Online Network (SHaRON)

SHaRON is a peer to peer ehealth therapeutic network connecting various individuals and supported by NHS clinicians, for people who have mental health conditions.

SHaRoN helps clinicians track and monitor clients' mood and progress 24/7, and spot possible signs of deterioration or changes in behaviour suggesting a relapse, for timely interventions. Clinicians are able to provide psycho-education to individuals and groups as indicated.

Clients provide peer education which keeps them actively engaged with their care and is beneficial to recovery.

In addition to reading governance and policy documents, clinicians receive two hour practical training sessions to develop confidence and skills in moderating an online platform. Clinicians who are not digitally savvy are offered individual and group clinical and management supervision through Skype to introduce them to the use of a digital intervention.

https://www.sharon.nhs.uk/

> In future, remote delivery of care to patients in their homes will become more prevalent via telemedicine.

10.0 Theme 3: AI and Robotics

Over the next two decades there is great potential for AI to improve healthcare[12]. The remarkable promise of AI is particularly centred on machine learning, including deep learning[13].

Machine learning is a branch of AI that allows computer systems to learn directly from examples, data, and experience. Deep learning enables computational models that are composed of multiple processing layers to learn representations of data with multiple levels of abstraction.

As computer processing power continues to progress, machine learning will generate patient, clinician and health system benefits from the vast amount of healthcare data available today. Machine learning is advancing at such a rate that it can now outperform humans on some specific tasks. Actionable intelligence will be extracted to better predict, prevent, screen, and diagnose disease. AI and machine learning will facilitate treatment tailored to each patient.

Carefully designed AI algorithms will also enhance NHS productivity, through large-scale process optimisation, clinical pathway streamlining and public health applications. By offloading some human tasks to machines, when appropriate and properly validated, clinical workflow and productivity could be greatly improved throughout the NHS.

Advances in medical software and hardware are accelerating the field of clinical robotics. Current uses of robotics in the NHS extend significantly beyond automating repetitive tasks and include minimally invasive prostate cancer surgery, a robotic radiotherapy system (that minimises damage to healthy tissue) and 3D printed bionic arms for amputees[14].

On the horizon are robotic technologies including soft robotics, robotic platforms for microsurgery, advanced robotic endoscopy, capsule robots and wearable robots including exoskeletons. Rehabilitation and assisted living robots which can help patients recover from stroke or support people with dementia are also being developed[15].

10.1 The patient

The introduction of AI enabled virtual health coaches which incorporate behavioural science can nudge patients towards a better lifestyle and help them to manage their medications, reducing the overall risk specific to an individual patient. Unified personal records that integrate the increasing amount of patient-generated data with electronic health records will benefit patients by allowing health prompts to be delivered remotely, enabling patients with long-term conditions such as asthma, diabetes, or heart failure to self manage better. Patient specific prediction of disease progression and smarter appointment scheduling will also be possible.

AI is enabling patients with mental health illness to access therapy services from any internet enabled location (including the patient's smartphone) at a time of their choice. Natural language processing technology, a form of AI, is being used to enhance CBT through real-time online conversation with therapists[16].

Emerging robotics technology includes an advanced bionic arm, small enough to fit children as young as nine. New manufacturing techniques based on 3D scanners and printers, radical reduction in fitting time, and the advanced functionality of the limb are gradually changing the way prosthetists, orthotists, occupational therapists and physiotherapists work with patients.

Patients must be able to access education and technical support in how to set up and best use new digital technology. Improved patient education and support could be facilitated either by creating new professional roles or through upskilling clinicians in the community, for example pharmacists, primary care nurses and health visitors.

Patients must be able to access education and technical support in how to set up and best use new digital technology.

10.2 Healthcare professionals

Healthcare professionals spend anywhere between 15 and 70% of their working time performing administrative tasks. AI systems will in the near future be capable of ordering tests, compiling medical notes and completing other administrative tasks. These AI systems will provide the NHS with the biggest productivity gains and will allow healthcare professionals to focus on the clinical tasks that patients consider uniquely human, giving more time for patient-clinician interaction and communication.

AI, machine learning and robotics technology will support clinicians in delivering safer, higher quality care. Machine learning enabled early warning systems are used in hospitals to alert clinicians to patients at risk of deterioration, allowing them to deliver treatment that prevents severe illness, as recently demonstrated for sepsis management[17].

Deep learning technologies have already shown expert-level performance in medical image analysis, in domains such as screening for breast cancer, skin cancer or eye diseases[18]. Whilst radiology, pathology and ophthalmology are frequently cited as the disciplines most likely to be influenced by AI tools, the impact will inevitably affect all specialties and every clinician from doctors to nurses, pharmacists to paramedics and beyond.

All clinicians should be educated in the ethical standards and good practice of working with AI, best practice in data curation and governance and the interpretation of clinical statistics and recommendations generated by AI systems. The NHS needs AI specialists who understand the requirements of patients and healthcare professionals and are keen to be embedded in all care settings, so that AI systems designed for healthcare are fit for purpose.

The AI-enabled future ophthalmologist

The number of optical coherence tomography (OCT) scans in the UK needing analysis is set to rise dramatically and scans are increasingly being performed by community optometrists. Deep learning algorithms have been trained to identify pathology automatically from OCT scans, enabling robust early detection and triage of sight-threatening diabetic retinopathy and age-related macular degeneration. The use of this technology in clinical practice would greatly enable both ophthalmologists and optometrists, streamlining their capacity and capability to treat the most at-risk patients, and allowing them to enhance their own diagnostic skills through learning from the technology.

Chief Clinical Information Officer

The NHS appointed the first Chief Clinical Information officer (CCIO) in 2016. The CCIO role has subsequently been rolled out across NHS Provider Trusts. CCIOs support the strategic aims of the Trust for clinical engagement and adoption of technology, focusing on patient outcomes and productivity to continuously improve patient care. CCIOs are providing a clinical voice to the implementation of Electronic Health Records. CCIOs usually have over 10 years' experience as a healthcare professional, usually as a doctor or a nurse with additional experience in direct clinical systems and process re-design.

10.3 Health system

Potential applications of AI to improve systems efficiency and productivity include optimisation and prediction of patient flow through the hospital; improvements to the current efficacy and efficiency of procurement; and enhancement of workforce logistics and service planning. AI will also increasingly be used to monitor public health trends, identifying initiatives that have a positive impact on population health.

A key goal of using AI technologies must be to integrate, analyse and personalise digital data in order to provide health services in the community, such that treatment in hospital becomes increasingly unnecessary. Advances in the vision abilities of machines, if sensitively deployed, and remote monitoring should enable patients to be safely cared for in the comfort of their own homes, by staff educated and trained in ways of working in modern, non-centralised, health systems. Remote monitoring has the clear potential to reduce the need for acute hospital services.

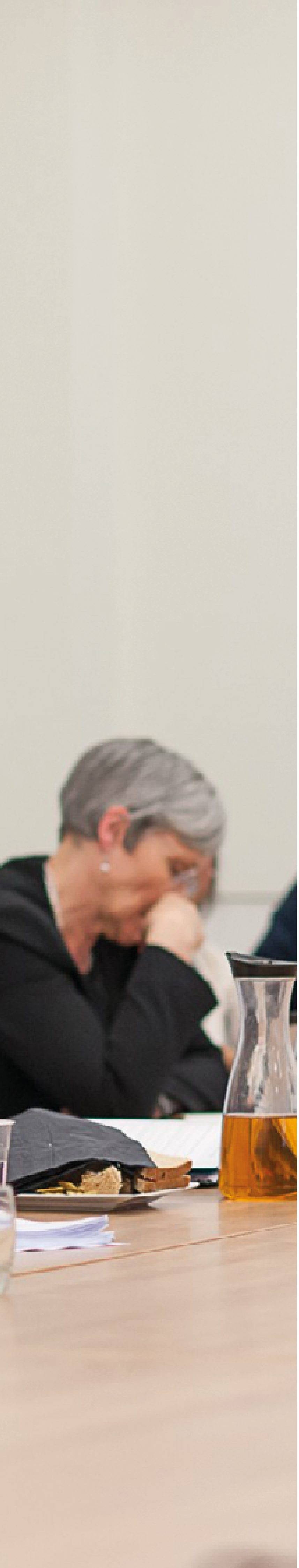
One of the NHS's greatest assets is its comprehensive datasets. For AI and machine learning to realise the potential benefits of analysing these datasets, the NHS needs a high quality, secure, information infrastructure, explicitly co-designed and agreed with the public, which has the ability to aggregate and integrate patient generated information with data across different health and care settings.

The NHS is starting to develop this infrastructure through its local health and care record exemplar programmes. Since 2016, Chief Clinical Information Officers - clinicians with additional experience in re-designing health systems - have been appointed in the NHS to try to ensure that only user-friendly electronic health records meeting current and future patient needs are implemented.

Using better integrated electronic health datasets, machine methods have been shown to better predict clinical risks in various, particularly complex, diseases. These methods are also capable of better tailoring therapy to the needs of an individual patient. Additionally, machine learning could facilitate research that reduces health inequalities through finding therapies for complex patients frequently excluded from clinical trials; for example the elderly, or patients with multiple health problems.

> "While it's hard to predict the future, we know artificial intelligence, digital medicine and genomics will have an enormous impact on improving efficiency and precision in healthcare. This review will focus on the extraordinary opportunities to leverage these technologies for the healthcare workforce and power a sustainable and vibrant NHS."
>
> Dr Eric Topol

Dr Eric Topol at work with the Technology Review Panel



11.0 Open call for evidence

We have identified a series of questions as part of an open call for evidence. We invite responses from any organisation or individual able to inform the thinking of the Review.

Please join in the conversation at **Topol.hee.nhs.uk** where you will be able to find a set of questions to start the conversation.

The closing date is Wednesday 29th August at 12.00 noon.

This Interim Report is the beginning of the conversation. Evidence and comments are being sought from any organisation or individual with an interest in workforce education and development, with a view to informing the Final Report.

This will be submitted to the Secretary of State for Health and Social Care in December 2018. Wider engagement on the findings is planned from January 2019.

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Figure 1

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https://digital.nhs.uk/data-and-information/publications/statistical/general-and-personal-medical-services/as-at-31-december-2017-provisional-experimental-statistics

NHS Digital - NHS Workforce Statistics, December 2017
https://digital.nhs.uk/data-and-information/publications/statistical/nhs-workforce-statistics/nhs-workforce-statistics-december-2017

Figure 2

NHS Digital - NHS Workforce Statistics, December 2017
https://digital.nhs.uk/data-and-information/publications/statistical/nhs-workforce-statistics/nhs-workforce-statistics-december-2017

Figure 3

HEE - Facing the Facts, Shaping the Future - A draft health and care workforce strategy for England to 2027 (Figure 18, page 76)*, https://hee.nhs.uk/sites/default/files/documents/Facing%20the%20Facts%2C%20Shaping%20the%20Future%20%E2%80%93%20a%20draft%20health%20and%20care%20workforce%20strategy%20for%20England%20to%202027.pdf

*'Funded Posts' lines removed

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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'. (Taken from van Duin and Bakshi, 2017)

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

Assay data generation
Information generated through 'an investigative procedure in laboratory medicine, pharmacology, environmental biology and molecular biology for qualitatively assessing or quantitatively measuring the presence, amount, or functional activity of a target entity'. (Taken from Wikipedia, 2018)

https://en.wikipedia.org/wiki/Assay

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)

http://www.oed.com/view/Entry/13081?redirectedFrom=augmented+reality#eid33893672

Automatic speech recognition technologies
'Concerned with models, algorithms, and systems for automatically transcribing recorded speech into text'. (Taken from the University of Edinburgh, 2015-18)

https://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)

https://www.ntnu.edu/physics/bionano

C

CB - 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. (Taken from the interim report).

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)

https://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.)

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

Cognitive computing
'Systems that learn at scale, reason with purpose and interact with humans naturally. It is a mixture of computer science and cognitive science – that is, the understanding of the human brain and how it works. By means of self-teaching algorithms that use data mining, visual recognition, and natural language processing, the computer is able to solve problems and thereby optimize human processes'. (Taken from Sommer, 2017)

https://www.ibm.com/blogs/nordic-msp/artificial-intelligence-machine-learning-cognitive-computing/

COPD – Chronic Obstructive Pulmonary Disease
'The name of a group of lung conditions that cause breathing difficulties'. (Taken from NHS Choices, 2016)

https://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 (e.g. classification) and/or unsupervised (e.g. 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)

https://en.wikipedia.org/wiki/Deep_learning

Diagnostic and therapeutic modalities

'Methods of therapeutic approach and diagnosis'. (Taken from Wikipedia, 2018)

https://en.wikipedia.org/wiki/Modality

Diagnostic odyssey

Instances in which rare diseases go undiagnosed and 'affected individuals and their families are faced with a search for answers that can last for years'. Involves 'many different tests and consultations with clinicians across multiple specialities'. (Taken from Health Education England, 2018).

https://www.genomicseducation.hee.nhs.uk/news/item/428-rare-disease-genomics-and-the-future/

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)

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

DNA

Deoxyribonucleic acid – '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)

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

G

GDN - Genetic Diabetes Nurse

An initiative using experienced diabetes specialist nurses to help integrate genetic findings into diabetes care. (Taken from interim report).

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 National Institute for Health Research, 2016)

https://0-genomemedicine-biomedcentral-com.brum.beds.ac.uk/articles/10.1186/gm421

http://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 non-coding 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)

https://customercare.23andme.com/hc/en-us/articles/202904600-What-is-the-difference-between-genotyping-and-sequencing-

Germline variant
'A variant present at the point of conception. The variant is there present in every cell of that individual and can be passed on the next generation'. (Taken from the Genomics Education Programme's Whole Genome Sequencing Glossary, n.d.)

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 whilst 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.)

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

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.

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

MODY - Maturity Onset Diabetes of the Young
'A rare form of diabetes which is different from both Type 1 and Type 2 diabetes, and runs strongly in families. MODY is caused by a mutation (or change) in a single gene. If a parent has this gene mutation, any child they have, has a 50 per cent chance of inheriting it from them'. (Taken from Diabetes UK, n.d.)

https://www.diabetes.org.uk/diabetes-the-basics/other-types-of-diabetes/mody

Medical Virtualists
'Physicians who will spend the majority or all of their time caring for patients using a virtual medium'. (Taken from Nochomovitz et. al., 2018)

https://jamanetwork.com/journals/jama/article-abstract/2664528

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)

https://www.ucsfhealth.org/education/understanding_your_risk_for_heart_disease/

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

MOOCs – Massive Open Online Courses
'Freely accessible and open-licensed short courses, delivered to large cohorts of learners fully online'. (Taken from The University of Edinburgh, 2018)

https://www.ed.ac.uk/studying/moocs/about

N

Natural language processing
'Takes an advanced neural network to parse human language. When an AI 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'. (Taken from Greene, 2017)

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

O

OCT - Optical Coherence Tomography
'Non-invasive imaging testing. OCT uses light waves to take cross-section pictures of the retina'. (Taken from Turbert, 2018)

https://www.aao.org/eye-health/treatments/what-is-optical-coherence-tomography

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).

http://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)

https://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

Sequence-based assays of somatic variation
Investigative laboratory medicine based on the sequence looking at somatic variation – 'a variant arising in somatic cells (all cells in the body other than those that lead to the production of gametes) which can therefore not be passed on to the next generation'. (Taken from Wikipedia, 2018 and the Genomic Education Programme's Whole Genome Sequencing Glossary. See also Assay data generation.)

https://en.wikipedia.org/wiki/Assay

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

https://customercare.23andme.com/hc/en-us/articles/202904600-What-is-the-difference-between-genotyping-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'. (Taken from Rouse, 2017).

https://whatis.techtarget.com/definition/smart-speaker

SPOCs – Small Private Online Courses
A 'version of a Massive Open Online Course used locally with on-campus students' (see also MOOC). (Taken from Wikipedia, 2018)

https://en.wikipedia.org/wiki/Small_private_online_course

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).

https://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.).

http://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)

http://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)

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

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

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Genomics

- **Professor Sir Nilesh Samani** BSc MD DSc (Hons) FRCP FACC FESC FMedSci DL
- **Professor Mark McCarthy** MA MB BChir MD FRCP(UK) FSB FMedSci

Digital Medicine

- **Professor Rachel McKendry** BSc, PhD
- **Professor Lionel Tarassenko** CBE FREng FMedSci FIET MA DPhil

Artificial Intelligence and Robotics

- **Dr Hugh Harvey** MBBSs BSc(Hons) FRCR MD(Res)
- **Professor Mihaela van der Schaar** PhD

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Appendix 1 – The Review Board

Name		Role
Dr Eric Topol MD	**Chair**	Executive Vice-President of the Scripps Research Institute, Professor of Molecular Medicine, and the Founder and Director of the Scripps Translational Science Institute
Dr Hugh Harvey MBBSs BSc(Hons) FRCR MD(Res)	**Co-chair - Artificial Intelligence**	Consultant radiologist, RCR AI working group, Clinical Director at Kheiron Medical Technologies.
Professor Mihaela Van der Schaar PhD	**Co-chair - Artificial Intelligence**	Man Professor of Quantitative Finance in the Oxford – Man Institute of Quantitative Finance in the Department of Engineering Science at Oxford and Faculty Fellow of the Alan Turing Institute, London
Professor Rachel McKendry BSc PhD	**Co-chair - Digital Medicine**	Professor of Biomedical Nanotechnology at UCL with a joint position at the London Centre for Nanotechnology and Division of Medicine. Director of i-sense, Director of Biomedicine at the London Centre for Nanotechnology
Professor Lionel Tarassenko CBE FREng FMedSci FIET MA DPhil	**Co-chair - Digital Medicine**	Head of Engineering Science Department and Professor of Electrical Engineering, University of Oxford; Adjunct Professorial Fellow, Nuffield Department of Population Health
Professor Sir Nilesh Samani BSc MD DSc(Hons) FRCP FACC FESC FMedSci DL	**Co-chair - Genomics**	Professor of Cardiology, University of Leicester, Consultant Cardiologist, Glenfield Hospital Leicester and Medical Director British Heart Foundation
Professor Mark McCarthy MA MB BChir MD FRCP(UK) FSB FMedSci	**Co-chair - Genomics**	Robert Turner Professor of Diabetic Medicine; Group Head for the Wellcome Trust Centre for Human Genetics & Oxford Centre for Diabetes, Endocrinology and Metabolism
Professor Trudie Roberts	**Educationalist**	Director, Leeds Institute of Medical Education
Professor Luke Vale	**Health economist**	Health Foundation Chair in Health Economics Chair of the joint economic methods group of the international Cochrane and Campbell Collaborations
Ms Elizabeth Manero	**Public and Patient Involvement Lead**	Solicitor by background and Member of the HEE Patient Advisory Forum since 2012.
Mr Patrick Mitchell	**Senior Responsible Officer**	Regional Director for the South of England at Health Education England (HEE).
Mrs Sue Lacey Bryant BA Hons Dip Lib MSc FCLIP	**Programme Manager**	Senior Advisor, Knowledge for Healthcare, Health Education England.

Appendix 2 – Key participants

Professor Sir John Bell GBE FRS FMedSci	**Subject Matter Expert**	Regius Professor of Medicine, University of Oxford and Life Sciences Champion for the UK
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Mr Andy Gill	**Programme Manager - Genomics**	Deputy Head of Strategy, Health Education England
Dr Keith Grimes	**Subject Matter Expert**	General Practitioner and Digital Healthcare Consultant, IC24 Ltd.
Mrs Julie Honsberger	**Programme Manager- Digital Medicine**	Head of Training Programme Management, Health Education England
Professor Dame Anne Johnson	**Subject Matter Expert**	Professor of Infectious Disease Epidemiology, and public health expert, UCL
Dr Pearse Keane MD MSc FRCOphth MRCSI	**Subject Matter Expert**	Consultant Ophthalmologist, Moorfields Eye Hospital
Professor Neil Lawrence BEng, PhD	**Subject Matter Expert**	Professor of Machine Learning, Sheffield University (currently on leave as Director of Machine Learning at Amazon)
Professor Rose Luckin BA(Hons) PhD ACIB	**Educationalist**	Professor of Learner Centred Design
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Professor Pietro Valdastri PhD	**Subject Matter Expert**	Chair in Robotics and Autonomous Systems, School of Electronic and Electrical Engineering, University of Leeds
Professor Peter Watkinson	**Subject Matter Expert**	Consultant in Anaesthesia and Associate Professor of Intensive Care Medicine and joint clinical lead for the Critical Care Research Group, University of Oxford
Professor Alan Winfield BSc PhD CEng MIET MIEEE	**Ethicist**	Professor of Robot Ethics, Bristol Robotics Laboratory, UWE Bristol
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Notes

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