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SKILLS AND EXPERTISE GAPS FOR AI-BASED MEDICINE

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AI-based MedTech innovations are rapidly developing in a significant number of European countries, and they are likely to pervade the healthcare system soon. However, while it can be confidently assumed that technological advances in AI technology will continue, how readily and efficiently these advances can be assimilated into the clinic is less clear. To maximize the benefits of these technologies, the healthcare ecosystem, and in particular, **its workforce, must be prepared**.

We have reviewed the skills and expertise required by doctors, nurses and allied healthcare professionals across Europe. We have found that a **whole range of digital and AI skills will be required**, from basic use and security awareness for everyone to high-level development skills for design, validation and maintenance. This gap is likely to be compounded by additional factors such as the predicted **need for thousands of more data scientists** in the very near future, a **lack of trust** from the medical staff, **insufficient user knowledge**, and poor access to modern and efficient IT technology. In addition, preliminary evidence shows that current medical students might be less likely to choose specialties that are more likely to be affected by AI developments due to concerns around job security, therefore **risking short-to mid-term recruitment of** clinicians to fields with greater application of AI.

Among the solutions proposed to overcome this challenge, cross-disciplinarity and collaboration play a key role. For healthcare professionals, this may involve introducing **new combined medical degrees** including computer science aspects, as it is **already being done** in countries such as the Netherlands. For data scientists, it may require **developing attractive career pathways** within healthcare-focused alliances spanning healthcare institutions, academia and industry.

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1. WHAT SKILLS AND EXPERTISE WILL HEALTHCARE PROFESSIONALS NEED TO ENABLE SUCCESSFUL INTEGRATION OF NEW AI-BASED HEALTHCARE APPROACHES?

Healthcare professionals and allied health professionals across Europe will require a spectrum of key digital literacy skills to navigate the data-rich environment of a digital healthcare system supported by the AI revolution. The depth and breadth of such skills will vary according to each professional's level of engagement with modes of care transformed by AI, but there are themes common to all. Health Education England (HEE), an executive non-departmental public body sponsored by the Department of Health and Social Care, has released a Digital Capability Framework designed to support the improvement of digital capabilities of all healthcare professionals which provides a relevant framework for assessing the particular skills required for the AI revolution [1]. It is recommended that all healthcare staff should work towards a high level of digital literacy and technical proficiency, broad knowledge of the concepts of AI and where AI may have an impact on clinical care. The requirements within different digital domains will vary according to the differing roles of staff, and these are summarized in the proceeding paragraphs. A pan-European framework with a broader focus has been released by the European Commission to enhance the digital competency of all European citizens and support confident, critical and responsible use of digital technology [2].

Creation, innovation and research

Staff involved in the conception, design and implementation of AI solutions will need high-level skills in digital engagement and data analysis for the design, testing, validation and maintenance of machine learning algorithms. However, all staff will require varying levels of skills leveraging AI solutions to foster creation and innovation. Managerial staff will require experience interfacing with AI solutions to assess these strategically and extend the promise of AI solutions to risk management, developing business cases incorporating AI solutions. Patient facing and front-line staff will require sufficient familiarity with the concepts of AI to assess clinical scenarios where novel AI solutions could be deployed to drive superior clinical care and enhanced patient safety.

Information, data and content

All staff will need skills to find, manage, organize, store and share digital information, data and content. All staff will need an awareness of data integrity, data security and privacy including data provenance, curation and principles of information governance for optimal use of AI solutions and compliance with relevant regulations, such as the EU General Data Protection Regulation (GDPR EU 2016/679). Staff implementing and utilizing AI solutions will require sufficient expertise to critically appraise the applications and robustly assess the validity of software and algorithms. Implementation staff will require the capacity for integration of AI solutions with legacy information technology, current data usage and infrastructure access.

Teaching, learning and self-development

All staff will need basic digital literacy including the awareness of digital security and the influence of different AI software solutions relevant to their role. Staff will use digital platforms and tools for further education and professional development, utilizing a wide range of digital technologies to communicate with peers, colleagues and stakeholders and to understand the different function and purpose of different methods of digital communication. Staff will need to be engaged with a culture of lifelong learning and continual re-development as the pace of integrated AI solutions quickens. Medical education and training will need to evolve to accommodate the assessment and treatment of increasingly complex cases. As the population ages, it is anticipated the complexity of clinical care will increase as patients accumulate multiple comorbidities requiring multiple treatments. AI is well placed to assist clinicians managing such complexity, for example with algorithms to predict medication interactions and risk of adverse effects from medication combinations to manage polypharmacy [2]. Policy makers across a range of areas of expertise including law, ethics, finance, consumer psychology and behavioural economics will be key stakeholders in contributing to the development of public policy that guides the deployment of AI in healthcare. There are a range of training opportunities for staff across such broad backgrounds to increase their understanding of AI, both on a pan-European level such as the AI course from the European Centre for Technology [3] and within member states, such as the innovative "1% programme" in Finland [4] aiming to train 1% of the population, or thousands of experts from non-technology fields, to remodel Finland's economy toward the incorporation of AI.

Communication, collaboration and participation

All staff will require the ability to use a wide range of technical devices in a personal and professional context both individually and across collaborative tasks with their peers and colleagues. Clinical and patient-facing staff will need skills to interpret the output of machine learning solutions, such as genomic tests or clinical risk prediction algorithms, and to communicate the results of these to patients and carers with varying levels of information literacy. This will include discussions canvassing probability and risk, interpretation of results and communicating their uncertainty, for example, what a particular positive result from any algorithm may or may not mean. Critical in this will be the necessary social skills to assess the levels of digital literacy of patients, carers and the use of novel technology solutions to improve the communication of clinically impactful results.

Table 1. Examples of skills and expertise healthcare professionals will need to enable successful integration of new AI-based healthcare approaches (adapted from Health Education England (HEE): A Health and Care Digital Capabilities Framework [1])

	Medical staff	**Nursing staff**
Creation, innovation and research	Assessing diagnostic utility and validity of novel AI diagnostic solutions	Identifying where areas of unmet clinical need can be met by AI to foster innovation
Information, data and content	Curating the structure of data inputs (medical records, clinical notes) to substantially enhance the power of downstream algorithms	Providing guidance to colleagues on data integrity and the use, editing, storage and sharing of data
Teaching, learning and self-development	Using digital tools and technologies to support offline learning (classroom-based, work-based, etc.)	Using digital tools and technologies to support the education of patients and their carers
Communication, collaboration and participation	Discussing with patients and carers the capacity and limitations of predictive algorithms	Discussing with patients and their carers how to use and monitor novel AI devices (e.g. wearables)

2. CURRENT SKILL GAPS WITHIN HEALTHCARE

Current skill gaps and resource shortfalls may limit the readiness of healthcare systems for the widespread introduction of AI solutions across Europe. However, the introduction of AI solutions itself has the potential to address some of these gaps and shortfalls.

Current staff shortages are a critical area, with 100,000 currently vacant posts (1 in 11 posts) across the United Kingdom's National Health Service (NHS), including 10,000 doctors and 36,000 nurses [5]. The shortfall continues to worsen, with projections for a staffing shortfall of 250,000 by 2030 [5]. Central investment in education and training has fallen from 5% of health spending in 2006/7 to 3% in 2018/19 [5]. The number of nurses in community services has fallen by around 14% since 2009, and the number of district nurses has declined by 45% over the same period [5]. Staff shortages have a compound effect: shortages in one discipline necessarily have an impact on other disciplines with, for example, a shortage of nurses increasing the demands on doctors and other clinical staff. At the same time, the current workforce is ageing. Across Europe, the share of medical doctors over 55 rose from 27% to 38% from 2011 to 2016 [6].

The distribution of healthcare staff also varies across Europe. The number of physicians per 100,000 population is considerably higher in some member states (>480 in Greece, Austria and Portugal) than others (<300 in Ireland, the United Kingdom, Romania and Poland) [6]. The number of nurses also varies dramatically, with >1,000 nurses per 100,000 in some member states (Germany, Ireland, Luxembourg, Ireland and Sweden) but <450 in others (Bulgaria, Slovenia, Greece, Croatia and Romania) [7].

The readiness of staff for interacting with AI solutions is also limited. Survey data from across all European Union member states from May 2018, including health facility staff, researchers, governmental health authorities and software developers identified perceived challenges to the adoption of AI solutions, with 13% of survey respondents citing a lack of trust from medical staff and 10% of survey respondents citing insufficient user knowledge [8]. There is a recognized shortage of data scientists with higher-level training in data analytics with the European Commission reporting an anticipated shortfall of thousands of data scientists by 2020 [9]. However, there is emergent interest in the dedicated training of data scientists and AI technical experts, with over 160 bachelor's or master's degrees in AI or closely related fields currently accepting students across European Union member states including courses specifically in the intersection of AI and healthcare, such as the MSc in Digital Health and AI (Bournemouth University) among others [10].

Current access to information technology and infrastructure is poor, with 60% of health professionals stating that current IT infrastructure within the United Kingdom's NHS is not fit for purpose, only 3% saying current systems are adequate, with vital patient-facing clinical time lost to technical failures such as slow computers or failing printers [11].

Population-level literacy and numeracy may also hamper the adoption of AI solutions, with some European Union member states having either average literacy (Italy, France, Spain and Slovenia) or numeracy (France, Greece, Italy and Slovenia) scores below the OECD average [12]. Specific data on problem-solving in technology-rich environments was captured in the OECD skill survey and found that on average 31% of the population had at least modest skills, higher in some states (Denmark, Finland, Belgium, all >35%) than others (Greece, Poland, Slovenia, Slovak Republic, all <30%) [12].

3. CHALLENGES TO ADDRESSING THE SKILLS GAP

The previous sections have established that a significant number of skills gaps will need to be overcome to ensure that healthcare providers across Europe are able to maximize the benefits of AI-based technologies for patient care. The following sections will discuss approaches that can and are already being taken in order to mitigate these gaps. However, prior to focusing on the likely solutions, it is necessary to consider both existing and future challenges that are likely to exacerbate the skills gap and may oppose measures aimed at addressing it.

These challenges can be broadly divided into three different domains: a) organization; b) incentivization; and c) managing disruption. Each of these challenges will affect the relevant stakeholders in different ways and will need to be proactively addressed to ensure skills gaps are mitigated in the most efficient and effective way.

Challenge 1: Organization – who is responsible for addressing the skills gap? The organizational challenge, in simple terms, relates to the questions: "who is responsible for solving the skills gap problem?" and "through what organizational mechanisms do they intend to solve the problem?".

Rather than focus down on individual European countries from the outset, it is worth considering whether or not any supernational European initiatives are focusing on addressing the skills gap around Europe. The European Commission functions as the executive branch of the European Union and is itself not responsible for driving its agenda. The European Union's political goals and strategies are developed collectively by its member states, and the Commission serves to translate them into policies and initiatives, covering areas including public health, digital health and the health workforce. Within digital health, the Commission published a communication in April 2018 focused on "enabling the digital transformation of health and care in the Digital Single Market; empowering citizens and building a healthier society" [13]. The communication highlighted the growing importance of digital health in general and discussed issues around data privacy and patient-centric health. It concluded that collaboration and active engagement between patients, health systems and the market would be key to realizing its potential. However, detailed discussion around the likely skills gap was out of its scope.

The communication highlighted that one of the key reasons "the health and care sector in Europe has so far been relatively slow in implementing and scaling up innovative solutions for person-centred care" is that it requires both "significant financial investment at a time when health and social care systems are under financial pressure" and "commitment and knowledge of how to ensure such an investment leads to successful and cost-effective implementation of digitally-enabled, person-centred care solutions", alongside favourable market conditions. This infers that these conditions have not been met and thus eludes to the skills gap, without directly defining it.

In terms of potential solutions, the communication includes reference to "provision of knowledge resources such as guidelines, tools, innovative and best practices as well as reference catalogues". An example of such a resource is the European Union-supported L-ead Summer School, a two-week educational experience developed by Semmelweiss University in Hungary and IESE Business School in Spain for developing e-skills of health workforce [14].

The first summer school took place in 2019 and was attended by 37 participants across the world. Much of the two weeks included interactive sessions discussing implications for the health workforce in the digital era.

Taken together, this would suggest that supernational efforts from the European Union are being made, but they are enabling in nature, rather than able to drive policy changes on addressing skills gaps at a national level. This, therefore, remains the remit of national policymakers and thus leads to the follow-on question previously proposed: "through what organizational mechanisms do they intend to solve the problem?".

The cross-disciplinary nature of AI poses a big challenge. Traditionally, within any national government organization, discrete bodies have existed in order to drive policy across finance, health, education and industry. All four of these entities (and likely others) would play a key role in addressing the AI skills gap in healthcare and it is therefore vital that these bodies work together as seamlessly as possible. Any policy changes are likely to be associated with an investment, either through financial, capital or human resource. A significant challenge for any new policy area that spans government organizations will be ensuring that appropriate leadership is in place to ensure the relevant investments can be made. In a critical area such as AI, governments are grappling with the questions as to whether it is sufficient for decisions to be made in this entirely cross-organizational manner or whether discrete entities need to be developed to help refine decision making and execution [15].

Different European countries have addressed this question differently. In the United Kingdom, the Office for Artificial Intelligence was formed in March 2018 which sits across the Department for Digital, Culture, Media & Sport and Department for Business, Energy & Industrial Strategy. Among its remit is to ensure that AI-related skills gaps are proactively addressed across the United Kingdom industries. Moreover, in February 2019, NHSX was formed which includes teams from across the key government United Kingdom health organizations, namely the Department of Health and Social Care, NHS England and NHS Improvement. NHSX has an investment of over £1 billion per year and focuses on digital transformation of the NHS.

In France, a national AI strategy was published in March 2018 and France chose to focus its efforts on four sectors in which to prioritize AI uptake, with healthcare being one [16]. Significantly, it was recommended that a Joint Centre of Excellence for AI at State Level be created which would sit within the inter-ministerial department of information systems (Dinum).

In Germany, the federal government's AI strategy was published in November 2018 having been jointly developed by the Federal Ministry of Education and Research, the Federal Ministry for Economic Affairs and Energy, and the Federal Ministry of Labour and Social Affairs based on suggestions from a nationwide online consultation [17]. Within the strategy, the role of AI in healthcare is noted and increasing the digitization of health records is highlighted as a key strategy. However, to our knowledge there is no discrete government entity in Germany which is tasked with developing AI-related policy.

Although smaller economies will be able to dedicate less resource to these areas it is notable that many of them are still developing an AI strategy, and, for example in the case of Lithuania, the role of AI in healthcare remains a key area for investment [18].

While these and many other mainland European countries have detailed overarching strategies and associated infrastructure to oversee the adoption of AI into healthcare, to our knowledge, there do not appear to be available any detailed centralized policies on actively addressing the skills gap, in contrast to the United Kingdom.

Challenge 2: Incentivization – how to retain and attract skilled and highly trainable individuals into healthcare? A critical issue that may further exacerbate the skills gap in the short to medium term are the incentives, or lack thereof, for relevant individuals to remain in or enter the healthcare sector. Although many of the relevant AI-associated skills can be learnt with the appropriate training and experience in order for the skills gap not to widen, it is essential that the majority of individuals that enter the health sector are capable and willing enough to develop these skills. Moreover, a significant proportion of pre-trained individuals and experts being recruited to and/or retained within healthcare will also be necessary.

An important challenge which is likely to disrupt policymakers' attempts to attract and retain the right skill-mix to the healthcare sector is the risk of jobs in the private sector being a far more attractive proposition for individuals compared to the public sector. This specific issue is addressed later in this article, and importantly highlights the key role collaboration across the public and private sector will play [19].

A parallel challenge, which forms the focus of this section, is how to ensure appropriately skilled/trainable individuals are attracted to work within the healthcare sector. A number of factors will dictate how attractive a career in healthcare will be; however, in the context of this article, the focus will be on factors that are directly associated with AI adoption.

There are widespread concerns that, in the longer term, an increasing use of AI may lead to job losses across healthcare, and this may deter individuals from entering or staying within the health sector [20]. A publication from 2019 describes results from a recent survey of 170 people in Switzerland, spread across medical students, surgeons and radiologists, exploring views on how AI was likely to disrupt the future of radiology [21]. The data illustrates some key differences in views across the different disciplines. One striking finding was that when asked "whether the profession of the diagnostic radiologist would be jeopardized in the future by new technical innovations such as AI", medical students were significantly more pessimistic than radiologists. The survey used a 21-point Likert scale (-10 to 10 with -10 = strongly disagree, 10 = strongly agree) and for this question medians for medical students and radiologists were 1 and -3 respectively (p=0.041). Though numerically this difference is not very large, it is notable that students appeared to agree with the statement whereas current radiologists did not. Indeed, only 15% of medical students stated they would consider radiology as a future specialization when asked, and 26% cited the future use of AI as one of the reasons not to choose radiology. Responses from radiologists were far more positive and 91% stated that in the current situation they would choose radiology as a specialization again, with 79% of them confirming an interest in future technologies, such as AI, as one reason for this. The paper's authors argue that more education around the perceived risks from AI should be delivered at medical schools to potentially address this mismatch.

Although it is not possible to make firm conclusions based on the results of a single survey, the results highlight that medical students are potentially less likely to choose certain medical specialties due to the risk of job losses as a result of AI. This is not altogether a surprising finding and one may expect similar answers for specialties such as histopathology [22]. It may be argued that the risk is real and that it is a positive aspect for the skills gap in healthcare, that medical students will then choose disciplines where there may be a greater need for doctors. However, on expanding the argument it may also be true that secondary school students are less likely to choose medicine if there is a fear that AI may disrupt the job market. Moreover, some trained clinicians may leave medicine altogether.

While these fears cannot be substantiated, it is also likely that the issue will be more complex. 79% of radiologists stated that they chose radiology because of technologies such as AI. This suggests that the types of people who will go on to choose careers in healthcare in general, and in particular areas with a strong AI focus, may be more engaged with technology adoption. This is likely to increase retention, make training more efficient and thus alleviate workforce issues. The fact that multiple factors may influence attraction and retention of healthcare professionals underscores the challenges for policymakers when workforce planning.

Incentivization will also play a key role in re-training individuals, as the need for informational technology and other related skills will increase for all healthcare professionals. Why should workers engage with these activities? If AI is perceived as a threat to jobs, will this negatively affect perceptions around its use?

On the opposite end of the spectrum, similar challenges around incentivization will be present for data scientists and other professionals with expertise in AI to work within healthcare. The earlier sections of this article have already highlighted skills gaps for AI-readiness within healthcare, but it is also true that skills gaps in AI exist across practically all industrial sectors in Europe, particularly in comparison to the United States and China. A recent McKinsey report entitled "Notes from the AI frontier: tackling Europe's gap in digital and AI" details at length the skills gap across Europe [23]. A Royal Society report on data science skills states that in the last five years job-listings for data scientists has risen by 231%

[24]. The healthcare sector will therefore have to compete with a wider market to attract data scientists.

Challenge 3: Disruption – how will the adoption of AI within healthcare alter the skills gap? Individuals are already factoring in the likelihood of AI to disrupt certain professions when making career choices. At the same time, as certain specialities become more efficient due to AI-based methods, for example radiology or histopathology, it is likely that job opportunities in that discipline will diminish. In combination, these AI-associated factors may at the same time lead to shortages and redundancy across the workforce, in a manner that will be constantly changing. Moreover, the disruption is likely to significantly affect workload for clinicians during this time and will shift the types of activities that healthcare professionals will be doing.

One may expect that relatively simpler tasks will change first as these represent lower hanging fruit for AI approaches to translate into the clinic. For example, computer-interpreted electrocardiograms (ECG) have been used for many years and their accuracy has improved dramatically over this time, but it is still only a screening tool and as it stands all ECGs should be interpreted and acted upon by trained professionals [25], [26]. However, traditionally, ECG interpretation was a core skill that was developed by junior doctors and specialist nurses through both educational activities, but more so through on-the-job experience. As ECGs are now increasingly automatically interpreted, this skill is not being developed in the same way. This risks a lack of expertise being developed for more senior doctors, where the expectation will be to interpret more complex ECG findings. Significantly, data has shown that incorrect automated ECG analysis increases the risk that humans will also make an error compared to if they reviewed the same ECG without an automatic interpretation available to view [27]. As clinicians have less opportunity to develop their own independent analysis experience, the likelihood of these errors may well increase. This example is likely to be applicable to other activities, such as interpreting blood results, and the risk of deskilling senior clinicians and allied health professionals of the future is one that must be proactively mitigated, though how this can best be done represents an unenviable challenge.

4. HOW CAN THE SKILLS GAP BE OVERCOME?

Having established that AI-related skills gaps exist, and are at risk of becoming worse across European healthcare institutions, the final section of this article will use a recent state-of-the-art review [28] into healthcare workforce planning as a platform for highlighting a range of strategies that may potentially be employed to alleviate the skills gap.

The Topol Review – an NHS-focused review on how to prepare the workforce for the digital future

One of the seminal pieces of work exploring how best the workforce can be prepared to best exploit the benefits of AI is included within a review recently commissioned by HEE. "The Topol Review: Preparing the healthcare workforce to deliver the digital future" was published in February 2019 [28]. It is a highly relevant piece of work which, while focusing on the NHS, provides a wide range of broad and tangible insights and recommendations that are generalizable across national healthcare providers.

The recommendations span digital health, AI and other associated technologies such as robotics. There is a large degree of overlap for each of these domains, but focusing on AI-readiness, three important themes appear to emerge: leadership and organization, education and collaboration. Each of these themes can be applied as part of the solution to the challenges that may exacerbate the skills gap in the previous sub-sections.

Leadership and organization

"The Topol Review" makes a number of recommendations associated with how organizational structures should be set up within the NHS to help develop and drive the changes needed to help ready the workforce in the United Kingdom for AI-enabled health technologies. It is recommended that leadership teams are developed at a national level and healthcare professionals should have strong representation within these in order to advise on opportunities and challenges. This is already taking place in countries around Europe, with Estonia's approach being a leading example. The Estonian e-Health Foundation Board is made up of multiple stakeholders including representatives from the Estonian Society of Family Doctors and Estonian Hospital Union [29]. The board has been responsible for overseeing the countries e-Health initiative which is regarded as developing one of the leading integrated health information systems within Europe, which has been optimally designed in order to leverage AI-based technologies [30].

"The Topol Review" recommends that at a local NHS Trust level, board-level responsibility should be assigned to ensure adoption of technologies is done effectively, with appropriate engagement from healthcare staff. The review acknowledged that the planning and commissioning of local services will vary nationally and autonomy in decision making, particularly in local workforce planning, will be necessary. Though any longer-term modelling exercises are likely to be fraught with uncertainty, somewhat ironically AI-based methods have also been developed to assist workforce planning and thus AI may itself be part of the solution [31].

Education

The importance of the education system in addressing the skills gap cannot be overstated. Again, using “The Topol Review” as a foundational platform for discussion: within it a number of recommendations are made (see Figure 1). One of the key recommendations is that an NHS Digital Education Programme be developed to oversee a national strategy. Moreover, a number of strategies for how best to prepare the future workforce are recommended which includes initiatives to support intercalation during undergraduate degrees to undertake engineering and computer science training. At the same time, it is suggested that students within those degrees should be engaged with to attract them to tackle health-related problems.

Culture

- Allow staff dedicated time for learning
- Develop multi-professional learning approaches

Educator support

- Develop a leadership team to provide strategic overview
- Foster leading educators of the future

Workforce development and education

- Establish NHS digital education programme
- Support staff to develop digital literacy
- Re-design curricula related to professional, statutory and regulatory bodies

Special workforce and teams

- Develop attractive career pathways and educational programmes for AI-linked specialist roles
- Nurture close industry collaborations enabling placements and industry exchanges

Training the future workforce

- Ensure AI part of undergraduate curriculum for healthcare professionals
- Develop a workforce with strong digital literacy skills
- Cross-disciplinary intercalated degrees across health, engineering and computing

Figure 1. Recommendations made in “The Topol Review” for training, education and skills development.

The impetus to change undergraduate medical degrees in order to better prepare doctors for the digital age has been gathering force [32]. A number of educational programmes to engage computer scientists with healthcare are also being developed, such as the European Institute for Innovation and Technology's (EIT) summer school for reinventing European healthcare [33]. The UKRI (United Kingdom Research and Innovation) has recently announced 16 centres for doctoral training (CDTs) in AI, most of which cover areas associated with healthcare and specifically four of them directly focus on healthcare applications (University College London, Imperial College London, University of Edinburgh and University of Leeds) [34].

One particularly innovative approach has been adopted at the University of Twente, where since 2003 they have been offering a degree in Technical Medicine [35]. The educational programme aims to bridge the gap between classical medicine and complex technology. The educational programme aims to bridge the gap between classical medicine and complex technology, and supports the development of technical physicians, who have "the knowledge, skills and problem-solving mind-set to design and safely apply improved diagnostics and therapeutics for the benefit of patients" [35]. Students are educated about and exposed to a range of technologies through the degree including novel diagnostic and interventional procedures (for example, interventional radiology), physical medical devices and software. Self-directed learning forms a critical part of the curriculum and this approach is aimed at ensuring that graduates continue to educate themselves in order to stay up-to-date with technical advances in their respective fields [36]. This degree provides an innovative blueprint for other educators to learn from.

Collaboration

Collaboration will be at the centre of narrowing the skills gap for developing AI and healthcare. Specifically, collaborations across healthcare, industry and academia will be key. One hurdle already discussed within this article and highlighted in "The Topol Review" is the scarcity of data scientists and potential difficulties in attracting them to healthcare. One incentive recommended is to develop attractive career pathways for higher specialist training for data scientists. However, this will need to be leveraged alongside genuine partnerships with industry. Healthcare institutions such as the NHS will need to consider engaging with potential collaborators. These institutions have the potential to demonstrate their value as a preferred partner, in view of the access to health data which is of such value to the technology industry. Clearly these collaborations will need to safeguard against exploitation but if enacted correctly they will prove critical in attracting cutting edge AI technology to address critical healthcare challenges.

Significantly, survey data from 907 data scientists in the United Kingdom highlighted that 56% of them were considering seeking new roles within 12 months. Although a number of reasons were cited for general job dissatisfaction, over 50% of managers cited that there was a great challenge in operating in siloed teams. This could potentially be addressed through a healthcare-based alliance and suggests that such collaborations may be attractive in improving job satisfaction for data scientists [37].

The UKRI Centres for Doctoral Training in AI are an exciting example of a collaboration across NHS Trusts, academia and industry and it will be intriguing to see the outputs that they can generate [34], [38]. The UCL programme offers a one-year MRes followed by a 3-year PhD embedded in an NHS setting. Similarly, the German Research Centre for Artificial Intelligence (DFKI) has developed a number of industry collaborations, and health applications are one of its key focus areas [39].

Scenario: Cancer diagnostics – a potential example of how clinical pathways will be disrupted by AI, and its implications for healthcare professionals

It's 2029. Sarah is a 53-year-old pharmacist in the UK NHS. She undergoes regular breast screening with mammography, but rather than at fixed two-yearly intervals, the frequency of her mammograms is personalized with a risk-adapted algorithm based on features from her last mammogram, which is more convenient, more cost effective, and reduces the risk of false positives [40], [41], [42]. All mammograms continue to be reviewed by two reviewers; however, one of the initial reviewers is now a deep-learning algorithm performing automated image analysis. For Sarah, the algorithm detects a suspicious breast mass and the second reviewer, a trained radiologist, agrees [43]. She undergoes surgery and recovers well. Her surgical histopathology slides are digitally scanned and assessed by automated image analysis to assist the pathologist in detecting any spread of her breast cancer to lymph nodes [44], [45]. In consultation with her treating oncologist, her tumour is sent for gene expression profiling and the data is analysed with machine learning algorithms, to help estimate her risk of recurrence and inform her decision for adjuvant chemotherapy [46], [47]. During her chemotherapy treatment, her oncologist carefully manages any toxicity from therapy supported by risk-prediction algorithms that predict her risk of mortality during chemotherapy [48]. Sarah uses wearable devices that can monitor her heart rate and blood pressure, that can alert her and oncologist remotely, to early signs of infection [49]. After completing chemotherapy, she requires adjuvant radiation therapy which is planned in part by AI algorithms that help map the dose of radiotherapy to minimize the side effects of treatment [50], [51].

Improving patient safety and reducing the clinical risk of treatment is a key area where AI and machine learning aim to improve Sarah's care. From risk-adapted mammograms reducing the risk of overdiagnosis and unnecessary diagnostic tests, optimizing her treatment decisions informed by risk prediction algorithms and avoiding unnecessary chemotherapy or radiotherapy for some patients, to enhanced monitoring during treatment to diagnose complications early, the quality and safety of Sarah's clinical care can be supported by AI and digital medicine.

During Sarah's diagnosis and treatment, she requires care from many healthcare professionals and the support of staff skilled in the interaction with AI and machine learning algorithms to complement and optimize her clinical care. The clinical interactions with AI range from direct involvement from the radiologist co-reporting her mammogram in conjunction with automated machine learning algorithms to her oncologist interpreting the results of predictive algorithms to accurately communicate clinical risk and inform therapeutic decisions, and to administrative and clerical staff accurately capturing treatment and clinical data to support the expansion of real world datasets that can inform future predictive and treatment algorithms. Staff will need different levels of expertise for their differing interactions with AI; however, all will require strong digital literacy, an awareness of the roles, opportunities and limitations of differing algorithms and continued learning.

5. CONCLUSIONS

The skills gap in Europe represents a potentially crucial barrier to adoption for AI-based technologies in healthcare. Without being proactively addressed, this gap may widen and national level leadership will be key in redressing the balance. It is clear that multi-stakeholder involvement, including engagement with healthcare professionals, will be required to ensure effective policymaking. In this regard, Estonia have set an excellent precedent through their e-Health Foundation Board. Moreover, although the European Union offers supportive initiatives for European countries, European Union-supported L-ead Summer School, the needs for each nation are likely to be unique. Each country should consider performing thorough objective appraisals of their own skills gap and "The Topol Review" commissioned by the United Kingdom provides an excellent example of how this can be performed.

The relative lack of data scientists and AI expertise is a particular challenge, but the healthcare sector also represents an attractive proposition for AI expertise to focus upon due to the validity of big data approaches and potential for patient benefit. Education will be key, and incentivizing a lifelong-learning approach for healthcare professionals will be essential given the likely rapidly evolving nature of AI. In addition, innovative collaborations within academia, such as with engineering and computing departments, and across academia and industry will be of significant value. The technical medicine degree in the Netherlands provides an excellent example of how knowledge and skills can be engendered within a medical degree in order to develop physicians best positioned to make the most of the rise of AI-based technologies.

Addressing the skills gap will not be simple, and there is likely to be ongoing disruption to the workforce as AI assumes an increasing role within patient care. However, the potential value for patients and healthcare institutions as a whole is undeniable, and a proactive approach by policymakers with a specific focus addressing educational needs and enablement of multi-stakeholder collaboration will be critical for these benefits to be realized.

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