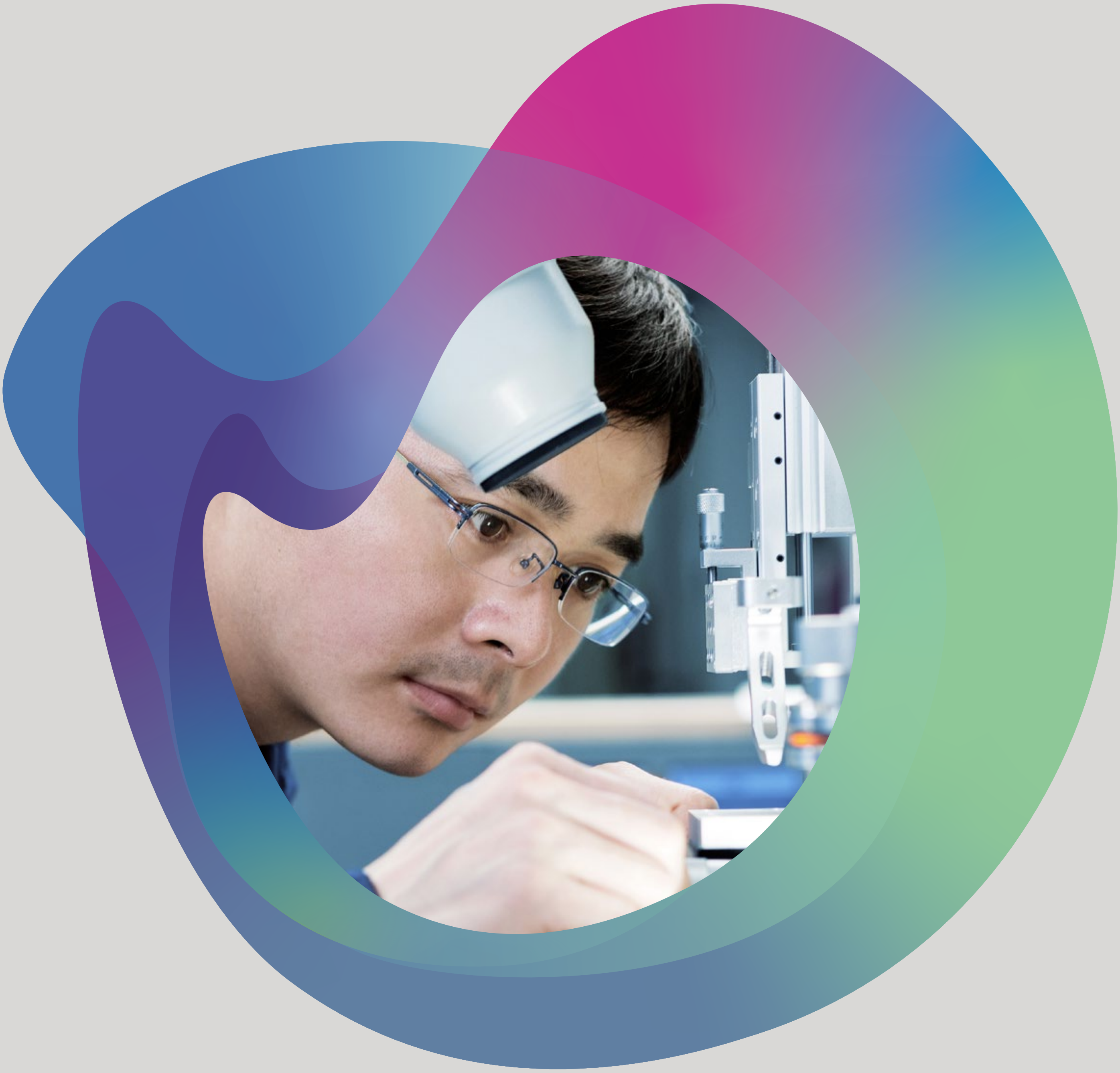
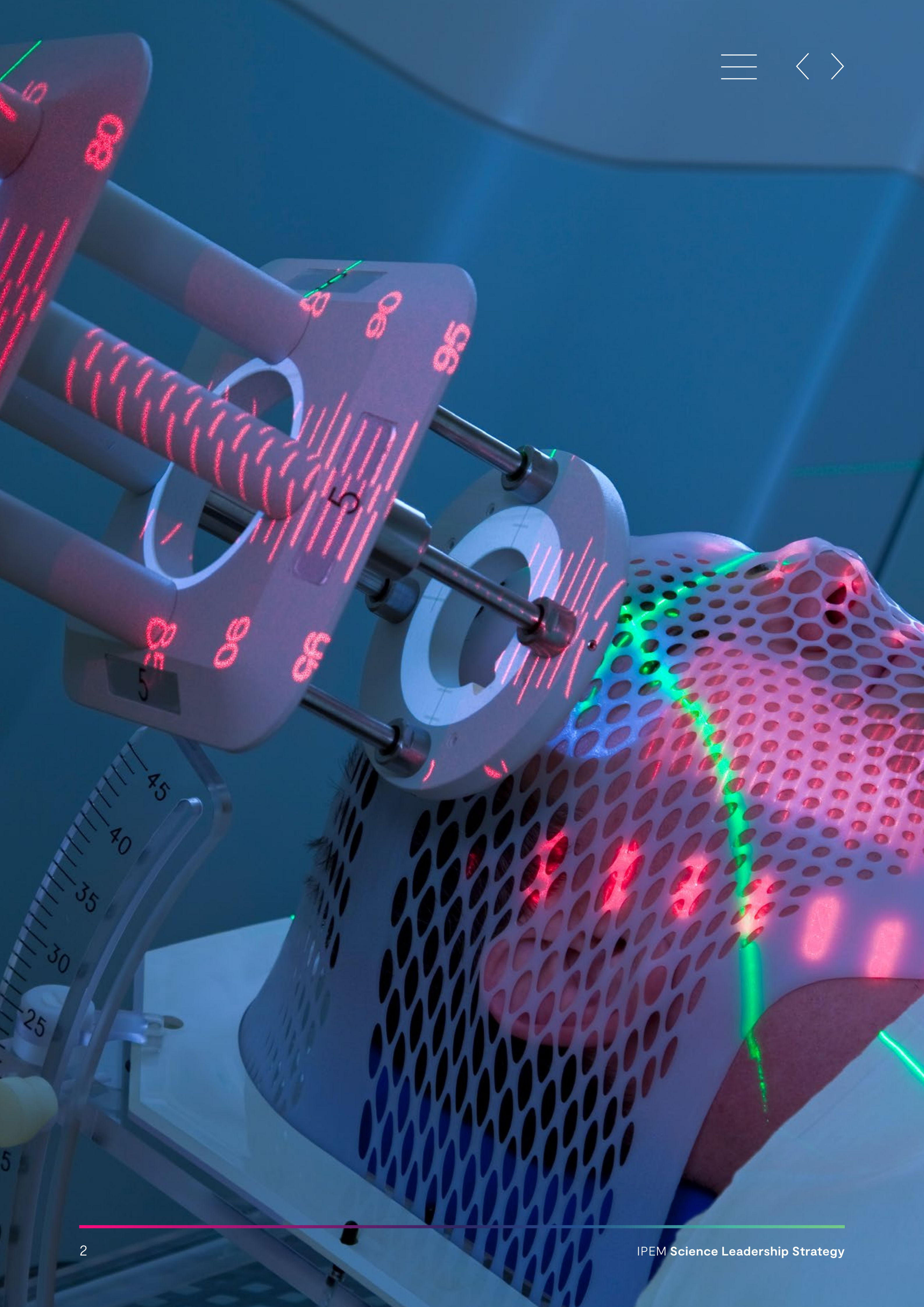
IPEM
Institute of Physics and
Engineering in Medicine



Science Leadership Strategy



Contents

Executive Summary

The Science Leadership Strategy will reinvigorate IPEM's scientific and technical activity to ensure we are relevant, engaged and engaging in a changing operating environment. It complements IPEM's 2025 strategy, particularly the *leadership* and *professional development* elements, but also gives focus and guiding purpose to public outreach activities and engagement with other professions.

Identifying future threats and opportunities will allow IPEM to take a more proactive approach: engaging early, leading conversations, anticipating and identifying gaps in policy and practice. We will use this information to engage with policy and decision makers early on to ensure our members' voices are represented where they can have a real impact.

The strategy defines three grand challenges and three emerging trends, and outlines the key issues that should be incorporated into our priorities and action plans:

Grand challenges are the major challenges that are increasingly affecting healthcare sciences:

— Climate change
- Carbon costing and energy costing essential services and resources
- Improving energy- and carbon efficiency of services without compromising patient outcomes
- Preparing to address the effects of climate change (extreme weather events and changing disease patterns)

— Staffing and workforce
- Demonstrating and advocating the value of physics, engineering, and technology in medicine
- Supporting skills development for the workplace of the future
- Exploring fluidity between disciplines and settings to promote retention of talented staff

— Safety and security
- Cybersecurity of cloud and edge systems, IoT devices and equipment
- Planning and protecting against resource scarcity
- Emergence of new data may expose new concerns with existing practices

Emerging trends are technologies, enabling platforms and ideas that could be harnessed to make a addressing the grand challenges and make positive changes to the health and care research and delivery ecosystem:

— Alignment and collaboration
  - Working with outside specialisms and organisations to push boundaries and develop holistic solutions
  - Promoting constructive discussion between academia, industry, and NHS to ensure clear routes to adoption and successful clinical translation

— Smart digitisation
  - Making use of increased data prevalence, richness and capability from home and health settings
  - Preparing for the rise of AI as an enabler of productivity and innovation, and a step into the regulatory unknown

— Personalised health
  - Empowering patients with their own health, while maintaining quality and equality of care
  - Increased individual and population-scale data from wearables, sensing, biomarkers and -omics
  - Combining individual data with population data and powerful computing drive towards preventative care

We will use emerging evidence from horizon scanning and the collective knowledge and experience of our members to ensure that we can deliver real impact through our events and the projects we fund. Intelligent use of this data will enable IPEM not just to address immediate problems but to explore new lines of scientific enquiry and remain a leading voice of physics and engineering in medicine.

Healthcare scientists and engineers hold core skills in scientific methodology, measurements and analysis and so are ideally placed to be at the forefront of change in healthcare in the coming decades. With coordinated effort alongside IPEM's overarching strategy this is a strong platform to raise the profile of IPEM's members and the value of the role they play and must continue to play to realise NHS and government ambitions.

Foreword

"Healthcare is changing. New and digital technologies are driving patient outcomes and will reshape professional practice and operating environments. Scientists, engineers, and technologists, as professionals in medical physics and engineering, ensure technological change is driven in the interests of patients. As part of a forward-thinking, engaged, and creative community of practice, IPEM members can shape this transformation and, in doing so, will underscore their relevance and value in healthcare's technology revolution.

As the role and use of new and digital technologies expands throughout the medical ecosystem, IPEM must ensure change and innovation is reflected in discussions among members, external stakeholders, and policy makers. This way we can ensure our resources, work plans and events help drive professionalism to serve the operating environments of today and tomorrow. We must be at the leading edge and informed of the breadth of activities taking place across the IPEM network and externally. We must be prepared for change in research and clinical practise to ensure we serve our members, champion the workforces we represent, and effectively deliver our charitable objectives.

By consolidating our strengths and focusing our efforts, we can ensure healthcare sciences are recognised, understood, and valued correctly. We will advocate for skills and training provision that is adequate to support a sustainable and thriving professional community. This should address technical skills, encourage creativity, innovation, and entrepreneurship, and develop transferable professional skills in communication, advocacy, and management.

The strategy is envisioned as a living, agile framework, personalisable to each specialism and supporting collaboration. It will adapt to respond to areas of interest and will help us shape the in-house policies and practices to get innovative ideas off the ground.

I look forward to engaging with you and bringing the Science Leadership Strategy to life."

Dr Robert Farley, FIPEM
President, Institute of Physics and Engineering in Medicine
2021-2023

1

Introduction

The Science Leadership Strategy aims to harness the strengths, future potential and breadth of skill and experience across IPEM's membership. It will support growth and change in professional development activity by identifying key challenges and trends, enabling a strategic approach to knowledge management and cross disciplinary collaboration.

By scanning the horizon, the Science Leadership Strategy will enable IPEM to respond to the grand challenges that lie ahead for physics and engineering in medicine and biology. It will help us grow our output, impact, and reputation, making the most of our existing resources and constantly seeking out new ideas. It will ensure new challenges, trends and technologies are part of the discussion across the IPEM's community, in wider STEM and public policy debates. In doing so it will enable a proactive, agile response to opportunities and challenges, offer ideas for future collaborations, guide the deployment of resources and show where IPEM can have the greatest impact.

Change in healthcare technology is driven by innovation, which depends on the flow of ideas, research, and resources. It can be held back by workforce pressures, poor communication, and the failure to translate ideas to action. IPEM will establish new ways to capture and communicate ideas to incentivise research and its translation into resources for professional development.

The Science Leadership Strategy will help streamline and accelerate generation, management, and dissemination of professional knowledge in IPEM.

— **Scanning current research and new frontiers**
  - Anticipating and responding to changing policy and regulatory and scientific developments
  - Leading discussion with quality, innovative professional knowledge output and events
  - Celebrating and exploiting our rich member network to create agile, cross-functional working groups
  - Exploring dynamics of change; actively identifying threats and opportunities to facilitate effective response

— **A joined-up approach and a strong voice**
  - Projecting a clear, consistent voice to grow IPEM's influence and reputation in the professional arena
  - Enabling constructive conversation with key partners and decision makers
  - Aligning externally to build partnerships, focus on key issues, and ensure professional value for membership

— **Setting in motion a change of approach that will allow us to be more flexible, creative, and agile while delivering our mission aligned to our values.**

2

The Strategy

Grand challenges and emerging trends

We want to be a strong advocate for change, and generate discussion and resources that are of value for our members. We must consider the operating environment at macro level to ensure we are able to act in a proactive and agile manner to shape the future we want to see. Some of the challenges and trends discussed here therefore apply outside healthcare innovation as they underpin broader societal changes that will impact government policy, funding decisions and resource availability.

The Science Leadership Strategy is designed around six topics:

3 grand challenges

The major challenges that will affect healthcare sciences in the near future.

3 emerging trends

Technologies, enabling platforms and ideas expected to make a significant impact to the health and care landscape.

	Grand Challenges		
	Climate change	Workforce	Clinical safety and security
Emerging Trends	**Alignment and collaboration** • Different disciplines and departments providing a seamless patient-centred pathway • Working with outside specialisms and organisations to upskill, reskill and bridge gaps • Promoting understanding and discussion between academia, industry and NHS to ensure clear routes to adoption and successful clinical translation		
	Smart digitisation • Increased data prevalence, richness and capability from home and health settings • The rise of AI as an enabler of workflow productivity and innovative technologies, and as a step into the regulatory unknown • Modular capabilities offering flexibility for expansion and development for agile translation and adoption		
	Personalised health • Empowering patients with their own health, while maintaining quality and equality of care • Increased individual and population-scale data from wearables, sensing, biomarkers and -omics • Combining individual data with population data and powerful computing drive towards preventative care		

Our ‘grand challenges’ are amongst the significant barriers to innovation and progress for our professions, requiring the development and adoption of new idea, technologies, and ways of working to address. Some are immediate, such as workforce in the form of staffing shortfalls, while others, like climate change, will develop and accelerate over time. Clinical safety and security are constant challenges in healthcare, where regulation, quality assurance and ethical review will need to respond and evolve with the shifting landscape.

These challenges are daunting, but they also bring opportunity. They will affect the entire healthcare ecosystem and wider society. As scientists, technologists, and engineers we have the collective capability to come up with practical or procedural solutions to some of these challenges, and the knowledge to know where steerage or mitigation is more appropriate. In both cases, this is a real chance to lead and shape conversation externally.

The biggest threat for healthcare sciences is inaction: as when policies, reviews and strategies are written to signpost improvements but are not acted upon. We must ensure that we unite behind the challenges and opportunities in this and future science strategies to populate the framework with ideas, translate this to deliverable actions and back this up with resource. Agreeing the signs of success will allow us to benchmark and record progress over time.

3

Grand Challenges

These external factors will shape the operating environment at local, national, and international levels and sit across specialties and sectors. They may not always directly influence what we do but should be considered in our future plans and actions.

Climate change and the environment

To meet emissions targets, we need to drastically reduce our emissions across all sectors, and reduce environmental impact in other ways (e.g. deforestation, water consumption and biodiversity)[1]. In the UK, this is set against a rapidly digitising economy and infrastructure and associated high energy demands. As digital technologies grow in number, reach and complexity, energy consumption will also grow. Urgent change is needed now to meet immediate goals and start a trajectory to meeting future challenges.

We are already seeing the effects of climate change. We need rapid and holistic – yet considered – response to mitigate against the effects we cannot avoid, and work hard to avoid those we still can. As engineers, scientists, and technologists, we have the mindset, the ingenuity, and the will to build solutions. IPEM's members are uniquely placed to provide these solutions within a framework that will also consider the implications for safety and patient care.

Long investment and equipment lifecycles in NHS are a key impediment to cutting emissions, and a financial burden. However, this creates opportunities for relatively smaller organisations such as IPEM to effect change by leading the way in funding small changes – our size confers agility.

We will use our networks and events to showcase regional success stories which can support colleagues in demonstrating scientific proof of concept to cascade transformation.

IPEM recently produced new environmental policies, and has a large and active Environmental Sustainability Group[2]. We will support this group in continuing their external-facing activity, including lobbying, leading studies, and producing advice, guidance and reports. Climate change is a practical reality best met with individual as well as collective action. To ensure sustainability is embraced as a core issue, we will encourage internal collaboration and consultation with IPEM's various strategic and working groups.

Greener NHS

The NHS has committed to reduce its carbon footprint in a push to become the world's first net zero national health service. The ambitious targets include a drive to reach net zero by 2040 for emissions the NHS controls directly, and 2045 for those it influences (*'NHS Carbon Footprint Plus'*)[3]. Acute care is responsible for a large proportion of NHS emissions, with medicines, medical equipment, and supply chain the biggest producers. Transition to net zero will therefore affect many of IPEM's members directly, and all members through wider repercussions for the medical physics and engineering communities. This includes things like sourcing and transport of raw materials; generation of radioisotopes; equipment operation and lifecycle management and journeys of staff and patients to deliver and access care, as well as use of disposable PPE and materials.

It is essential that reduction of emissions does not impact patient safety or care, nor compromise an already stretched workforce. Unlike other sources of NHS emissions, such as ambulances which may be replaced with electric vehicles and have optimised journeys, it is unclear how net zero will be achieved with many pieces of medical equipment. System complexity, high cost, quality assurance and safety, as well as long

product lifecycle contribute to this challenge. We will support efforts to achieve safe and effective carbon footprint in medical physics and engineering, whether this is through product design and development; quality procedures and assurances; or strategies for offsetting.

Decarbonising healthcare practice and research

The first step is to quantify the carbon cost of equipment and practices. A systematic approach to costing existing equipment and new technologies could be developed to create a resource similar to workforce calculators. Such a resource, developed from collective expertise or aided by a digital twin tool, could help encourage change that suits local services while supporting larger scale transformation with a consistent approach. The role of physicists and engineers in decarbonising healthcare spans design, development, and deployment. IPEM will ensure this role is recorded, recognised, and reflected in professional and public facing documentation and discussion. The scale of the challenge will require a wide range of skills and experiences, and the cross-disciplinary Environmental Sustainability Committee has an important role to play here. IPEM will also seek to support projects, collaborations and knowledge transfer networks looking to drive innovation in technologies and services.

Planning and mitigation

Climate change and efforts to address it will inevitably affect the way we live and work. This can manifest as the emergence of new diseases and conditions; shifting geography and demography of existing disease; and future epidemics. It is important to ensure that those designing, delivering, and interpreting diagnostic testing and imaging are aware of changes that may affect diagnosis or the downstream patient pathway. As a national and global community, we should also work to ensure that the lessons from the Covid pandemic are acknowledged and implemented in readiness for possible future epidemic or pandemic events.

Key topics to consider include:

— **Decarbonisation of healthcare science research, practice and supply chain**
  - The role of healthcare sciences in implementing 'Greener NHS'
  - Developing technologies and strategies to reduce the footprint

— **Sustainability**
  - Assessment and reduction of disposables
  - Ability to repair, reuse and repurpose
  - Energy efficiency and source versatility

— **Effect of climate change**
  - Changing disease patterns and emergence of new diseases, including those with pandemic potential
  - Extreme weather events threatening services.

Themes	Actions
Sustainability (disposables; energy use)	Guidance notes
Repair or replace?	Policy and position statements
Supply chain robustness	Round tables and white papers
Emergency preparedness	Lobbying for action, inclusion and detail

The health and care system in England is responsible for an estimated 5% of the country's carbon footprint[4]. The Greener NHS strategy sets out an ambitious set of targets but currently lacks detail on how these reductions will be achieved across the different disciplines and departments that make up the NHS. Modern science and technologies can be a very resource-intensive process, (e.g., cell culture and devices), and this trend may continue as we work to digitisation and our technologies become more powerful and energy-intensive in the pursuit of faster, higher resolution, more precise and more accurate diagnoses and therapies.

Workforce and skills

The pandemic has exposed severe workforce shortages across the healthcare sector, but this has long been a deep and enduring problem for physics and engineering[5,6]. This is beyond the scope of this strategy, but we do acknowledge the challenge that erosion of workforce and funding, coupled with increased targets, represents. Work to lobby, educate and advocate for improved staff coverage, particularly in the NHS will continue, drawing on information from horizon scanning exercises to present a compelling picture of future prospects.

We will use data from IPEM's Workforce Intelligence and Training unit together with on-the-ground evidence from members to lobby for improvements in current and future conditions. This combined approach will be data-driven but brought to life with real human stories, aligned where possible with external media and policy stories to increase traction. We will focus on aspects of workforce that we can directly influence within the short to medium term, supporting projects that see to increase capacity or freedom to innovate, or advance skills and knowledge in developing areas. We will work with stakeholders to assess the current skills landscape compared with pipeline training and projected demand.

We will explore ways of developing technical skills, either directly through focussed events, guidance documents and reports, or indirectly by working to influence training centres and employers such as the NHS. Led by members' experience and opinions, we will work with IPEM's membership team to develop career planning and progression management, so members feel prepared and supported in taking the next steps in a fulfilling career.

Reskilling: digital and AI literacy

We must ensure the healthcare science community – at all career stages – has the skills to keep up with digital, technological, and scientific change. Skills to invent, innovate, adopt and transform are the essence of science and engineering, but formal procedures must be broadened to embrace change.

Cloud computing, artificial intelligence and machine learning (AI/ML) and software applications are among the fastest growing areas for investment[7]. With appetite from individuals and health services, research and adoption will also see rapid growth. The key challenges here are ensuring that the existing workforce has the skills to fully embrace complex digital systems, and that training programmes prepare the scientists, technologists, and engineers of the future without compromising their core learning. Digital skills are in high demand in almost all areas, so healthcare sciences must be promoted effectively to attract and retain talent.

There are opportunities to exploit – digital technologies have the potential to improve rate and efficiency of research and development; reduce costs; and reduce workload, particularly through easing administrative burden and accelerating analysis. Scientists, technologists, and engineers with both technical and digital skills can engage effectively with clinical and IT or analytical colleagues. This will improve the visibility and perceived value of the healthcare sciences, and also offers opportunity to lead cross-functional teams in successful adoption, maintenance and improvement.

The digital skills gap is widely acknowledged, and a review by a research team at Coventry University highlighted the importance of introducing these skills (and confidence in them) at all levels[8]. They also noted communications between front and backroom staff were essential to improve data handling and analysis quality and efficiency.

The report recommended five training programmes to upskill NHS workers' digital skills:

1. **Training for senior managers to deliver a level of understanding on the importance and urgency of digital transformation, with enough information so that they can make strategic decisions**
2. **Training for frontline health practitioners to boost confidence, familiarity, and skills with digital technologies**
3. **Training to combat security concerns and deliver a basic knowledge of data analysis**
4. **Training on communication skills to address concerns surrounding communication efficiency between frontline and back-end (e.g., data analysis) staff**
5. **Training focused on improved data analytical skills within healthcare.**

Some of these are already firmly embedded within the healthcare sciences, giving a strong opportunity to demonstrate the importance of the professions to the education, training, and work sectors that interact with them. However, we cannot take this for granted and must ensure that knowledge of new systems allows skills evolution, and training programmes are designed to prepare the next generation.

Managerial and leadership skills

Growing numbers of healthcare scientists succeeding in leadership positions will help with value, visibility, and advocacy. To realise this, we will help members present strong candidacies for managerial or leadership roles and follow through with skills development and support needed to succeed. Many skills required can be evidenced through the myriad volunteering roles at IPEM, including outreach, conference organisation, committee membership and participation in Task & Finish groups.

Our *My Career Path* web resource, offered through the Engineering Council, is primarily a tool for recording CPD but it can also be used to record activities that will accumulate over time to help you reach the next stage in your career, whether that is a change to a managerial role, a promotion in a current role, or a move to a different specialism. Working with members and the Engineering Council we can develop this from CPD recording to longer term professional development and career planning.

Microlearning

Education can be time-consuming and expensive, and a comprehensive training course is not always appropriate or feasible. Microlearning is about learning small, focused pieces of information in a short time, for example, learning specific skills needed to advance a particular project. Understanding – through surveys, volunteer forums and conversation – what members need, and when, we can work towards targeted information sessions and webinars to address particular themes or areas that collectively represent a big barrier to progression.

Fostering a culture of innovation

We will review our prizes, awards, and bursaries portfolio to ensure it serves the professional community effectively and achieves our charitable objectives. Our resources are finite, but we can support projects beyond this portfolio through in-kind support. This includes:

- **Fostering links between fellow professionals or academic-industrial-clinical partnerships**
- **Developing skills that will help members access external support such as grants, fellowships, and entrepreneurial schemes**
- **Developing resources for members to present business cases for training, development or conducting research**
- **Increasing transparency and flexibility in our internal practices so we can respond in an agile, coordinated manner and facilitate useful links within membership.**

New ways of working

Greater adoption of technologies will continue to transform the way we connect and collaborate with each other, offering new opportunities for collaboration and innovation. IPEM is ahead of the curve here with online Communities of Interest, and geographically separated committees and working groups able to work remotely. However, we can do more for our members by making more intelligent use of our networks and connecting the right people at the right time. While there is fluidity in career options between academia and industry, the health service is more structured for a one-way flow of talent. This creates an unsustainable drain on the workforce that must be addressed. Again, this is beyond the scope of this Science Leadership Strategy, but we can seek to offer opportunities within IPEM that members may not receive in the normal course of work, aiming to create the freedom to pursue personal aspects of academic or professional interest. This includes research projects using data or other digital resource or, through funding or in-kind support, primary research.

Key topics to consider:

- **Advocating the role of science, technology and engineering in healthcare**
  - Building evidence and case studies of roles and research and development achievements
  - Quantitating workforce shortfall against productivity demands
  - Investigating and promoting or supporting research and technology development that increases accuracy, efficiency or capability of physics and engineering techniques in healthcare
- **Identifying and addressing skills gaps**
  - Developing our CPD platform to include professional development and career planning for all interests and tiers
  - Supporting skills development and evidencing for career progression and leadership
  - Identifying skills gaps in the workforce and training pipeline that threaten planned projects, targets, and adoption of future innovations
- **Promoting flexibility and fluidity between disciplines and sectors**
  - Signposting, facilitating, and supporting Knowledge Transfer Networks or Partnerships
  - Evaluating microlearning platforms to allow personalised, modular learning and development opportunities
  - Examining projects and evolving disciplines requiring particular skillsets in the context of training and career paths, CPD, professional development and evidencing

Themes	Actions
Addressing chronic shortages	Lobbying and campaigning
Promoting old skills and integrating new skills	Outreach
Lack of visibility	Engaging with education to increase routes to training
Career planning and professional development	Identify skills gaps and career pathways
Modernising workforce and workplace	Create and support networks and KTPs

Clinical safety and security

Safety is at the core of healthcare development and delivery, seeking to reduce risk through design and iterative development. It must evolve alongside and at pace with innovation, protecting workers and patients but not stifling progress. As we move into a new era of digital transformation, a human hand in development is no longer prerequisite. The need for robust moral, ethical and practical safety guidance and regulation is more important than ever to maintain a safe and secure environment for patients, staff, and wider society.

IPEM members' reports and papers regarding technical and workplace safety are highly regarded and respected. We will build on this by proactively identifying emerging or topical themes to investigate, drawing on current research, news items and policy announcements. This will help us to lead the conversation and increase impact by coordinating a response to resonate with professional and public interest. We will also work to modernise the access to – and indexing of – our professional knowledge outputs to increase visibility on search engines and harmonise with bibliographic software.

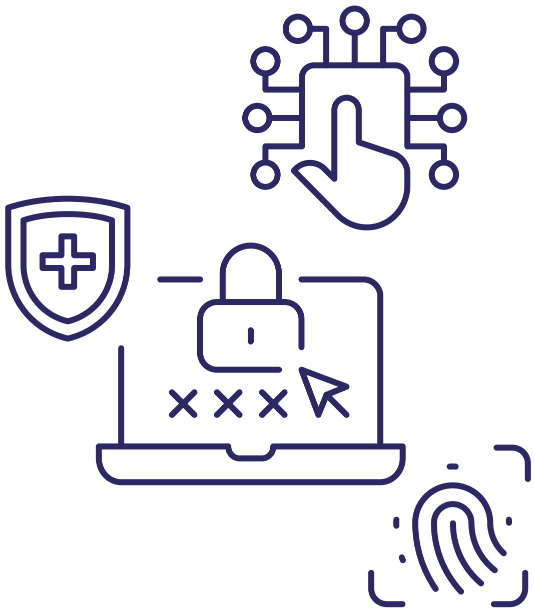
Drawing on members' expertise, interaction with SIGs and Communities of Interest (CoIs), and horizon scanning activity, we will work to identify topical and emerging themes that sit outside or across discipline boundaries. This will complement, not replace, existing SIG activity, giving members opportunity to experience their specialism from a different perspective, offering their expertise and learning from colleagues.

Themes that affect multiple modalities may be tackled by cross-disciplinary round table discussions and events, before being translated by working parties using the existing IPEM model. Breaking out of traditional silos will help us keep pace with innovation and introduce new voices and ideas, ensuring opportunity for members at all career stages to engage.

Cybersecurity

Integrity, availability, and confidentiality are paramount for any healthcare device or system. Patient data is a personal and highly sensitive resource and a lucrative target for criminal activity. The threat will increase alongside digitisation of the NHS and the systems and products that feed it. In the past there have been avoidable incidents arising due to failures in system design and staff training.

A 2020 Internet of Things (IoT) Threat Report found that 83% of medical imaging devices are running on operating systems that no longer receive vital software updates, including bug and security fixes[9]. Progress has been made in improving cybersecurity infrastructure, particularly with cloud-based systems, leading some analysts to predict a growth in attacks exploiting edge computing. In this instance, personnel represent the first line of defence. Computer- and data literacy are paramount, and those with science, technology and engineering backgrounds are well placed not only to respond but also to communicate with colleagues and ensure their systems and practices are robust.




REF. 1337/224
Auto Detection
Phase
Phase oversampling
Slice thickness
Slice oversampling

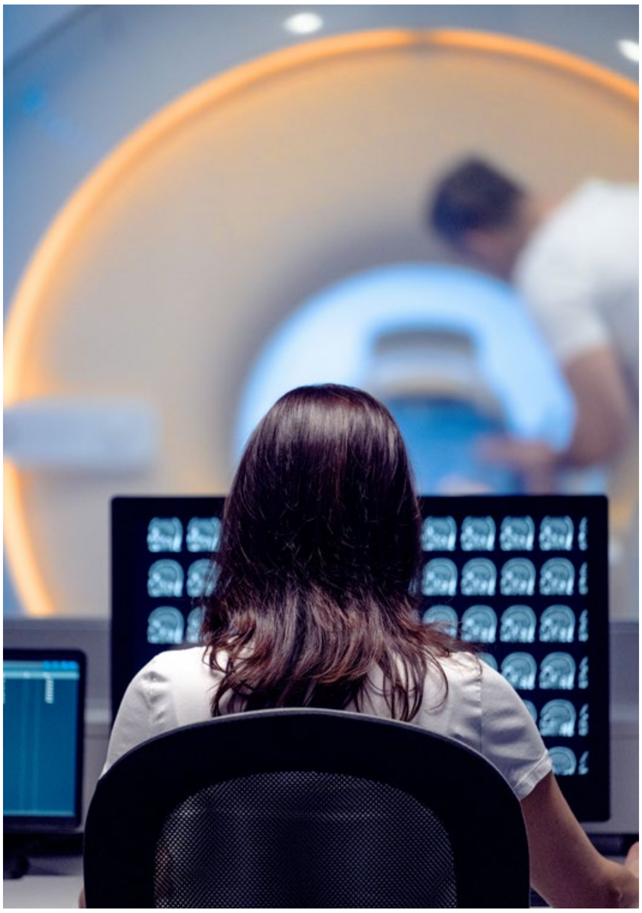
Resource scarcity

Medical research and delivery of physics- and engineering-based interventions can be resource-intensive activities. This can refer to high energy demand; something that may be addressed by developing more efficient operation procedures or by offsetting. It also refers to environmental, ecological, and political burden, for example associated with imaging modalities that require sourcing of raw materials such as radioisotopes and rare earth metals. Pipelines, and alternative sources, of critical materials like this must be secured for the future. It is also important to plan for scenarios in which supplies fail – what strategies may be taken; could other materials be used; could patient pathways be modified? Stress testing systems in this way can help avoid failures in safety and performance.

Resources, such as rare earth elements or medical radioisotopes used in imaging, are susceptible to supply issues related to climate policy, conflict, and politics. IPEM will continue to identify challenges and lobby for action. There is opportunity for us to act more strategically and proactively by scanning for and monitoring threats before they reach critical threshold; and also to generate public interest and discussion through white papers. We will create opportunities at events and meetings for this kind of critical analysis and futures thinking, alongside core activity addressing current challenges.

Emerging patient data

Although there are inherent issues around data protection and ethics, the massive growth of health data from diverse sources will offer new insights. In rehabilitation engineering, wearable sensors may be used to record continuous, real-world data into movement or device compatibility. Real-time analysis could detect and flag issues, helping make efficient use of patient contact time. Elsewhere, disease screening programmes could be targeted by monitoring biomarkers and detecting fluctuations. The ability to record and analyse data in this way extends the patient pathway at home, potentially also increasing operational efficiency and helping ameliorate workforce shortages. IPEM can support individual projects, from research to translation to critical review, through its varied grants and awards programme.



On a different scale, we continue to see data accumulating with decades of use of radiotherapy, nuclear medicine and non-ionising radiation. The core technologies of medical physics are still relatively recent and are constantly evolving. Longitudinal data at a population scale will augment current knowledge around the safety and utility of, for example, therapeutic and diagnostic radiation. This may offer opportunities to develop new technologies and interventional strategies; broaden the range of applications; or target and personalise dosing. Conversely, new information may emerge that presents new safety concerns or reduces the current scope. Guided by SIGs, we must monitor the landscape and prepare to adapt.

A new frontier of health regulation

Self-learning and AI-designed technologies will be increasingly present in healthcare; from software to connected devices to workflows and procedures. The ownership, responsibility, regulation and continued safety and quality monitoring of these systems represent interesting questions that will require cross-functional discussions.

Growing use of prescription and consumer healthcare and wearable devices offer increased quantity and richness of patient data, but the robustness and utility of this data must be considered. Modifications to devices or resultant data may need careful consideration from technical, clinical, and computational aspects.

Key topics to consider:

— Emerging longitudinal data

- Making use of data repositories and institutional knowledge to lead or commission studies
- Capitalising on new data sources to increase understanding of existing technologies, systems, and procedures
- Using horizon scanning and secondary research, and supported primary research, to identify potential threats

— Regulation of medical devices and SAMD

- Sharing resource and best practice for QA (quality assurance) and regulation of medical devices, including in-house manufactured devices; software and systems
- Considering 'safety by design' and 'equity by design' of medical devices, software and systems using cross-disciplinary teams
- The role of the professional in the ethical application of technology

— Cybersecurity

- Risk assessments and robustness testing for data repositories and sharing agreements; IoT devices and software
- Promoting the roles of clinical engineers and particularly clinical computing scientists in the safe and robust development and deployment of digitised or IoT devices
- Sharing knowledge and experience, internally and externally, to build both cloud and edge cybersecurity awareness and capability.

Themes	Actions
Emerging longitudinal data	Roundtables and white papers
Regulating medical devices, software, medicines and practices	Sharing best practice
Cybersecurity	Learning from collective experience and knowledge
Climate resilience	Advice notes and guidance documents
Resource scarcity	Reports and recommendations
	Evidence and horizon scanning

4

Emerging Trends

Enabling technologies and techniques will be key drivers of change in the operating environment for IPEM and its members. As with the ‘grand challenges’, they are top-level topics that capture drivers at a strategic level. In delivering the strategy, we will translate these general themes into targeted actions to address specific projects.

Alignment and collaboration

Filling vacancies and encouraging recruitment across different backgrounds with wide-ranging skills and interests will aid innovation and creative problem solving. Those who are multi-skilled, have an interrogating mindset and have the ability to work between disciplines and across different functions will be able to engage most effectively with new technologies and ideas entering the field or the workspace.

It is important to recognise that the current workforce and training scheme programmes focus on streamed skills development for particular specialised applications. The ability to communicate effectively with colleagues in other settings is therefore especially important.

> "Collaboration is often an effective way to ensure research impact" – UKRI 2022[10]

Healthcare has and is continuing to evolve to deliver more advanced, targeted, and accessible solutions. This broadening technology base is bringing in more people from different academic and professional backgrounds at different stages on the research, development, and deployment pathway, united by a goal of improving patient experience and outcome. We all need to be open to exploring these new interfaces and blurring boundaries – the best research and most effective translation will happen where pathways are considered fully with the most complete information from all stages. Visibility, open dialogue, and constructive problem solving are essential to the success of collaborative projects. This will increase understanding and awareness on all sides, and greater sense of ownership of new ideas and technologies.

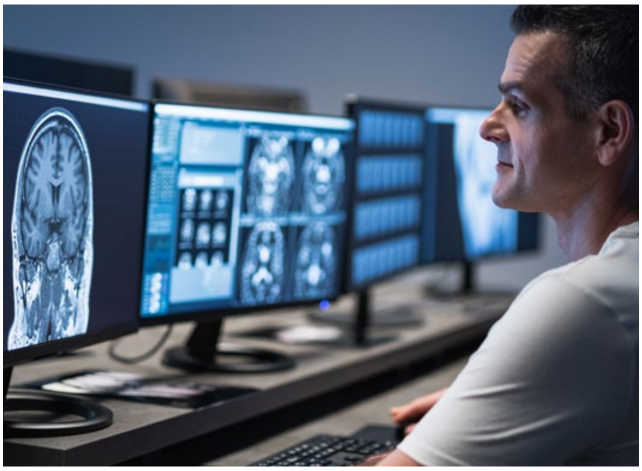
Organisations like IPEM have a strength and value in bringing together diverse groups – we can engage with a variety of stakeholders and draw on our talent pool to find a common language and develop robust, rounded projects. To do this effectively we need to be accessible, visible, and engaged. In the growing healthcare ecosystem, despite the myriad disciplines we represent there is more that unites than divides us. We will strengthen communications, relationships, and networks within IPEM by using online tools and in-person meetings to bring together people with complementary goals, skills, and ideas in response to particular challenges and need cases. Core groups like the SIGs and COIs will be valuable resources to provide detail and in depth understanding when needed.

This will play to the strengths of our professional community – combining scientific curiosity, creativity, and opportunity to meet new people, learn and grow. This will enrich portfolios and develop both soft skills and hard-edged CPD. The national office will support documentation of these experiences so they are reportable and valued within existing frameworks, both for trainees and more experienced staff looking to further their career, their interests or their opportunities to engage intellectually.

At a time of great workforce and economic strain, the value of collaboration is paramount to driving efficiency. It offers opportunity to develop experience in new or fringe areas, and helps upskill the workforce rather than reinforcing siloes through rigid training schemes. Engaging across boundaries can reduce confusion and opacity, develop career opportunities, and offer enriching professional experience.

We can expect a continuation of development of hybrid systems, such as SPECT-CT and PET-CT or -MR, as well as new technologies coming into play. We need to be ready to respond, embracing the opportunities they offer while gathering data to ensure benefits are translated in terms of workplace efficiency and patient benefit. Hybrid systems will require hybrid teams in research and development and the same cross- and inter-disciplinary skills to ensure successful clinical translation.

Advances in computing and data manipulation and analysis will translate through to the consumer and clinical healthcare markets, as well as augmenting research capability and throughput. Development may stay within traditional specialisms, but effective design is driven by understanding of the problem and the implementation user and landscape. This will require dialogue and understanding at different technology readiness levels and a willingness to engage at all levels. Longer term, skills that can bridge gaps between disciplines (soft skills as well as technical) will be increasingly important.



Case study 1

London Medical Imaging and AI Centre for Value-Based Healthcare is a consortium of academic, healthcare and industry partners[11]. Led by Kings College London, it was established to develop, test, and deploy pioneering AI systems across the NHS. Current projects include AI scan interpretation for coronary artery disease, software that renders 3D model from CT and MRI scans to enrich perioperative planning, increasing accuracy of contouring models for radiotherapy treatment planning, a detection tool for early-stage lung cancer from low-dose CT imaging, and predicting patient outcome from stroke anatomy using dynamic, large-scale data sets.

The centre's vision is to drive AIs and advanced imaging technologies into use in the NHS; use personalised diagnostics and therapies to transform health; and deliver economic benefit using AI enabled approaches for 'value based' healthcare, with potential cost reduction of up to 50% touted. The centre launched in April 2021 and will work to link vast amounts of patient data to deploy AIs at scale; address education and training challenges to prepare an AI-ready workforce, and build an ecosystem involving the academic and commercial sectors.

London has a rich tapestry of Trusts, universities and other organisations co-located which facilitates ready collaboration. The challenge is to replicate and disseminate across the country, particularly in more isolated communities, to ensure equitable access for healthcare scientists and patients regardless of postcode. Digital infrastructures and IPEM's online communities and member directory can help connecting the right people to support, develop and realise ambitious projects across the country and beyond.

Workforce visibility and integration

As healthcare becomes increasingly digitised, healthcare scientists in all settings will interact more closely will others, such as IT and data specialists, who may be directly involved with medical hardware, software and supporting infrastructure, but lack the clinical awareness to fully comprehend the consequences of design or performance modifications. Equally, people working in healthcare sciences may have variable IT skills and understanding of system performance and maintenance requirements.

Even those who are not involved with digital and IT infrastructure at a high level may benefit from constructive interaction. As an example, dose calculations for treatment planning are becoming increasingly complex, presenting a growth opportunity for computing. Clinical scientists and technologists involved in dose planning and delivery may not need to be able to build or interrogate the software or AI, but they should have the confidence that the outputs are accurate, safe, and not producing unexpected outcomes that affect downstream patient pathways. This might include thorough quality assurance and control (QA/QC), collaboration with computing colleagues who understand the algorithm, and collaboration with clinical staff who understand potential impacts to patient safety or radiation protection.

Case study 2

The National Robotarium is an Edinburgh-based Centre for Robotics and Artificial Intelligence, bringing together Heriot Watt and Edinburgh universities, clinicians, and industry to create innovative solutions to real-world challenges[12]. The centre acts as an incubator to support rapid translation of research from laboratory to deployment and places emphasis on entrepreneurship and driving digital skills development across its ecosystem.

In February 2022, the Robotarium was awarded £1.25m EPSRC funding to support research to refine definition of surgical margins for laparoscopic surgery[13]. Too generous and the surgery may fail to remove diseased tissue; too conservative and the patient may face increased recovery time or reduced function. Surgical margins are currently established through a combination of preoperative scans, surgeons' experience, and tactile probing during surgery (during 'open' or non-laparoscopic surgery), or frozen section pathology analysis which takes 15-20 minutes during the operation[14].

The project will bring together a wealth of expertise from laser manufacturing, fibre-optic sensors, computational modelling, and micromechanics to develop a mechanical imaging probe. It will seek to develop a micromechanical 'imaging' probe to assist in surgical margin definition in keyhole surgeries. The probe should reduce reliance on surgical experience as a variable and replicate tactile probing through minimally invasive incisions. It is planned to work in tandem with a 'mechanically intelligent' modelling framework – together, they are intended to allow real-time tumour identification and margin assessment.

Case study 3

Digital Health Ecosystem Wales (DHEW) takes a holistic approach to healthcare innovation and delivery and links up industry, clinicians, policy makers, academics, entrepreneurs, and funders across the country[15]. It offers a paid consulting service which aims to assist those developing new ideas and technologies in evidence generation to find a financial, commercial, or clinical footing for their work.

Projects include design of an advanced analytics work programme to support rapid, scaled delivery of objectives in the Digital Health & Care Strategy; a collaboration between NHS Wales Ecosystem, Dr Doctor and Patient Knows Best to develop a standard Patient Reported Outcome Measures (PROM) API and simplify future integrations, assessment on the impact of reduced face-to-face visits on the mental health of care home residents, MedTRIM: a peer-to-peer resource to support those exposed to trauma in the workplace and build resilience, a pilot study at Royal Glamorgan Hospital using RFID tracking to locate equipment in real-time, and development of a clinical chatbot tool to enable remote triage for musculoskeletal conditions.

Clinical computing scientists have an important role to play here. They are able to bridge the gaps between IT, data, and clinical specialisms and understand the requirements of each. We need to establish IPEM as a home for clinical and scientific computing and embed the specialism in our organisation to support the workforce and ensure wider membership can benefit from their knowledge and skills.

IPEM will work to promote the importance of protecting clinical performance and safety during 'digital transformation', for example with qualitative and quantitative data to paint a clear picture of the potential impacts of changes in IT hardware and software performance, maintenance and failures on equipment performance and safety to patients and staff. Case studies of positive collaborations and lessons that could be replicated more widely may also be useful resources for teams to advocate within individual workplaces as well as at a higher-level interacting with different professional bodies.

Knowledge Transfer Networks (KTNs) and Partnerships (KTPs)

KTNs and KTPs are initiatives developed by UKRI and Innovate UK to connect 'knowledge bases' across academia and industry. The networks comprise groups open to collaboration, leading to functional partnerships connecting ideas, expertise, and resources. There are funding opportunities for projects addressing particular challenges of national and international importance, such as antimicrobial resistance.

We want to help translate the untapped ideas and expertise held within our membership into tangible benefits for the medical physics and engineering community – whether this is developing effective materials for outreach and education; developing new work practices to improve outcome measure; or design or development of a new technology or piece of equipment. Our member network already holds the expertise needed to drive innovation and take new ideas through to clinical or commercial translation. IPEM will utilise this to bring dynamism to the network.

We will seek to create opportunities for people to bring their ideas to us and facilitate discussions that can identify next steps – whether that is establishing proof of concept, prototyping, testing. IPEM can create a similar functional knowledge transfer network within its membership or assemble teams to engage externally to answer broader healthcare challenges.

Key topics to consider include:

— Building internal relationships and networks

- Improving reporting between committees, working groups and wider member community
- Inviting and encouraging participation at all levels; broadening engagement opportunities beyond formal volunteer roles
- Helping members make meaningful, constructive professional relationships online and at in-person events.

Building external relationships

- Targeting access to the right people, at the right time, to assist:
  - User-led design
  - Contributing to standards, technical and advisory papers, and lobbying activity
- Coordinating IPEM representatives on external committees to best represent the organisation as a whole and effectively channel information

Scanning for and aligning with external activity

- Liaising with key stakeholders and allied organisations to pool resources and drive agenda
- Monitoring developments in strategy and policy of organisations that will impact medical physics and engineering in the short-, medium- and longer-term future

Building impact through supporting technology development and translation

- Expanding resources and professional knowledge curation to include data, code, and media
- Supporting translational research
- Supporting collaboration between clinic, industry, and academia
  - Targeted user-led design improves translation with a 'soft-landing'
  - Opportunity for joint grant application, development work or trials
  - Professional, personal and career development opportunities
- Invitation to innovate – open calls for projects to tackle grand challenges, discover and develop emerging technologies, and advance physics and engineering in medicine
  - A future-facing portfolio of prizes and bursaries
  - Central coordination of collaborations, KTNs and KTPs
  - Data-driven research using IPEM's online file sharing resources.

Themes	Actions
Interoperability	Building relationships between disciplines
Deepening understanding and developing skills	Facilitating project- and topic-led collaborative teams
Sharing data (research) and best practice (QA) Supply chain robustness	Facilitating knowledge transfer networks (KTNs) and partnerships (KTPs)
Sharing ideas to start new conversations	Developing relationships with external stakeholders
Expanding into interdisciplinary and emerging areas	Engaging with external activities in policy and strategy development
Advancing technology and user readiness levels	Aligning communications and activities (e.g., with media interest) to maximise impact
Delivering real change – acceleration, translation, adoption	
Strategic timing and placement	

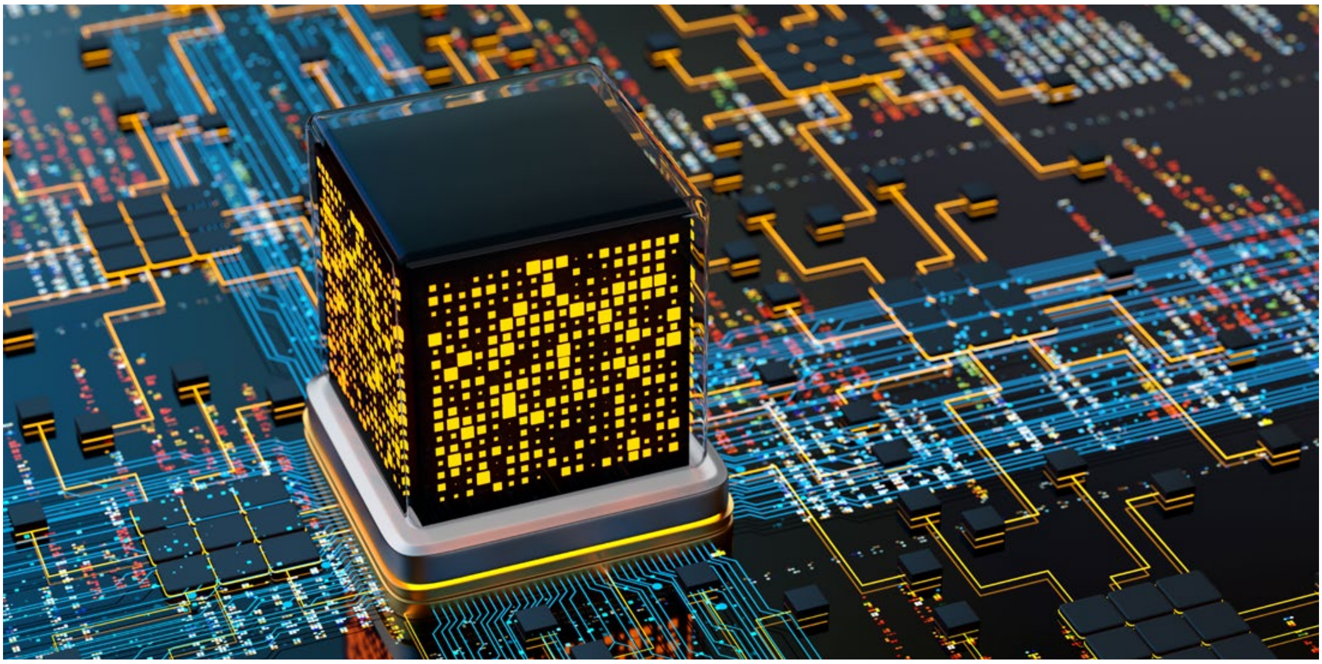
Smart digitization

> “Digital transformation is at the ‘top of the national agenda’”
>
> – Matthew Gould, Chief Executive NHSX, February 2022[16]

With development of smart cities, growth of consumer health devices, NHS digital transformation and Big Tech moving into the healthcare domain, digital technologies and solutions are set to affect every facet of healthcare directly or indirectly.

Smart digitisation is about ensuring transformation occurs in a pragmatic, joined-up way that enhances productivity and performance. 90% of all the world’s data to 2013 was generated in just two years – equating to 2.5 quintillion bytes of data every day – and the rate has only increased in the decade that followed[17]. The challenge is to make sense of this data and convert it to meaningful learning and practical output. This requires huge computational power; the ability to filter data for quality, robustness and inclusion criteria and the ability to analyse it effectively before any conclusions can be drawn or acted upon. Healthcare science has been central to developing and implementing digital technologies and already has a wealth of skills. This creates a strong platform from which to build.

The concept of machine or artificial intelligence has existed since at least the mid-20th century, but until recently has been hampered by cost and compute limitations. Increased capacity, capability, and the growth of cloud computing and IoT have accelerated research, translation and utility of AI and machine learning algorithms in the last decade. This trend is only set to continue as society increasingly digitises and networks. On the horizon, quantum computing offers a tantalising glimpse of computer systems powerful enough that can exceed human capability and not simply multiply or accelerate it. However, this potential comes with a dark



side – in an already contentious space, quantum technology could enable AI to develop to a point beyond the understanding of users and the explanation of designers. In the same way that 'safety by design' has been adopted as an industry standard for other medical devices[18], standards for the safe, ethical, and effective design and delivery of AI and machine learning must be agreed. This is particularly critical to healthcare, which holds some of the most precious, personal, and potentially exploitable data. For the workforce, it is important to establish clear lines of responsibility.

Besides regulation, AI systems require validation. Systems that are capable of learning in deployment may develop and deviate from the original design in potentially unpredictable ways in response to local population trends. Training data quality and diversity, system interrogation and modelling, and QA/QC evaluation will be important to assure output veracity and compatibility between systems. This will require constructive dialogue between those using the systems, using the data, developers, and IT managers.

Case study 1

Every year in the UK, there are around 55,000 diagnoses of breast cancer[19] and over 11,500 deaths from the disease[20]. Routine NHS mammographic screening of a target demographic is estimated to reduce number of annual deaths from breast cancer by about 1,300[19]. However, people with dense (fibrous or glandular) breast tissue are at a higher risk of breast cancer. Poor contrast on mammograms also makes identifying neoplasms more challenging in dense breast tissue and reducing success of screening. A Dutch team recently reported the use of a deep learning model to differentiate breasts with and without lesions and triage accordingly. They used data from an earlier multi-centre study in the Netherlands, the Dense Tissue and Early Breast Neoplasm Screening Trial, to develop and train a deep learning model to distinguish between breast tissue with and without lesions. The model correctly identified 90.7% of MRIs with lesions as abnormal and triaged for radiological review. It also identified 40% of lesion-free MRIs as normal and did not miss any cancers. While the accuracy and sensitivity have room for improvement, the authors demonstrate feasibility for AI deployment in screening programmes[21].

As MRI is a less reliable screening tool for people with dense breast, using a machine learning or other AI algorithm to identify those with dense breast (more likely to occur in those with lower body mass index or taking hormone replacement therapy) could reduce radiographer workload by preferentially suggesting an alternative initial screening method with higher sensitivity in this subset of the population.

Regulations and governance for transparent, understandable, auditable, and explainable AI are already in discussion, and it is imperative that artificial intelligence in medicine is developed and deployed in a way that serves and protects both patients and staff. IPEM's community of scientists, technologists and engineers is uniquely placed to lead the discussion here, covering the spectrum from research, development to translation; benchtop to workshop to patient; and together have the ability to explore and understand every stage of technology and patient pathways.

As Big Tech increasingly moves into the Med Tech space, the need for moral, ethical, and legal regulation will only increase. Developing skills, and experience in-house to deal with these systems is important to set the stage for mutual trust, fruitful collaboration and, when needed, the ability to question and campaign.

Under the digital transformation plans, digital technologies will continue to embed and grow, accelerated by rapid enforced adoption during the pandemic. The technology exists for this to become a connected and intelligent ecosystem

Case study 2

Researchers at MIT have been teaching a four-legged robot called 'Mini Cheetah' how to walk – largely without moving at all. Rather than meticulously hand-coding line by line, they used digital twins to 'run' using a subset of AI using reinforcement learning. This is essentially a high throughput trial-and error technique, where actions that lead to a desired outcome (such as stability or speed) are rewarded, allowing an autonomous system to become 'self-learning'. Virtual terrains were developed to allow the simulations to experience effects of movement on different types of surfaces – for example, more tentative steps might lead to more stable gait on an uneven or a very low friction surface. After 4000 simulations – or 3 hours of virtual training, equivalent to 100 hours of real-world training, the team ported what the virtual robot had learned in simulation to the physical robot. In this instance, the reinforcement learning was designed to reward gaits resulting in speed, and the robot managed to hit a personal best of 9mph[22, 23].

Digital twins allow specific testing and training of various scenarios in a virtual environment. They are essentially identical copies of real systems created in the virtual world.

They can allow destructive testing techniques without the costs, or for testing equipment that is impractical to access because of cost, geography, legality, or safety. For medical equipment and devices, digital twins may be used to increase research access without risking patient safety or confidentiality. The UK Government launched a National Digital Twin programme, hosted by the University of Cambridge, in 2018. This will form an ecosystem of interconnected digital twins to increase infrastructural resilience, optimise resource use and improve quality of life across the UK.

Reinforcement learning is a way of training desired outcomes in machine learning. Combining digital twins with reinforcement learning can rapidly accelerate development by removing the waits and costs associate with physical testing, and allow multiple scenarios to be processed in parallel limited only by compute power.

The robotics has interesting application in gait analysis modelling and prosthesis design, while the twinning and modelling has broad utility across the healthcare research environment.

– the challenge is to ensure there is a culture of willingness to embrace and engage with the interoperability digitisation can bring. This will mean sharing ideas and information between different disciplines, specialisms, and setting, developing the skills to interface effectively with these groups, and working to protect against vendor lock-in.

Edge computing and edge AI spans centralised, cloud-based data centres with devices outside the cloud that operate closer to physical things and people. This brings opportunity for machine learning based closely on the local population or even an individual patient in, for example, AI-enabled medical devices.

There are also threats, including cybersecurity and the challenge of regulating and creating a robust QA framework for centralised algorithms that are likely to diverge in different local deployments. This could potentially occur within the same NHS Trust with heterogeneous patient populations.

IPEM will seek to offer opportunities to learn and work between traditional groups; facilitating meetings between industry, academia and NHS; and creating platforms to educate and influence the wider healthcare ecosystem and policy makers.

AI is the enabler, not the solution

AI is not a panacea that can fix everything that is wrong in healthcare, and indeed it has the potential to exacerbate existing problems (bias; silos; overinterpretation or under interrogation of data) and create new ones if not designed and implemented correctly with a collaborative and holistic approach.

However, AI does have the potential to make a real impact in many areas of medicine and healthcare – from drug discovery to remote triage; big data analysis for public health to medical image 'reads', interpretation and reporting. It is important to ensure those who interact with AIs, as users or recipients, have confidence in the systems and their outputs. This will require education, outreach, and engagement – and working to ensure that AIs are fit for purpose, understandable, explainable and a framework for regulation and quality reporting exists around them.

> “Now is the moment to put data, digital and technology at the heart of how we transform health services for the benefit of citizens, patients and NHS staff”
>
> – Wade-Gery Review, 2021[24]

AI is growing and evolving concurrent with implementation – AIs are already being trialled and used in the NHS for applications such as analysis of brain MRIs for Alzheimer’s disease detection[25]; analysis of CT scans in cancer diagnosis[26,27,28]; replacing second radiologist reads to increase throughput efficiency[29]; and a tool designed to identify patients at risk of cancer to assist early detection[30,31,32]. However, effective regulation and legislation is lagging behind implementation[33].

We must act quickly to agree design, regulatory and ethical requirements and secure a seat at the table for healthcare scientists in the regional, national and international discussions that will take place to create frameworks for current and future AI technologies.

Case study 3

Data from NHS Digital is being used for research into the impact of Covid-19 on those living with cancer. The data, from the National Disease Registration Service and national population health datasets, is hosted in a trusted research environment (TRE) made available through DATA-CAN, the UK’s Health Data Research Hub for Cancer[34].

TREs help regulate the use of data by granting access to a secure, centralised source rather than access by download, where security may be compromised and downstream disclosure may occur without safeguards and assurances of confidentiality and ethical conduct. The NHS Digital TRE is supported by government investment of up to £200m to enable secure, efficient access to NHS data. This has the potential to improve access to quality, accurate data and support clinical research and trials across the NHS, academia, and industry in an efficient and ethical manner.

The data will be used to study the impact of Covid on the referral, diagnosis, treatment, and outcomes of patients with cancer throughout the pandemic. The insights from this research may be used to demonstrate the direct impact of the pandemic and inform lessons for seasonal Covid resurgences or future public health emergencies. Beyond Covid, it can help shape patient pathways for future cancer patients by finding precise evidence to support new services, tests, treatments, and workflows.

Proliferation of IoT, sensors and devices

Alongside medical devices used in or issued from healthcare settings, there is a growth in consumer devices with healthcare applications, such as monitoring activity and vital signs. Variability and lack of transparency in the quality, consistency, robustness, and completeness of the data limits utility in a clinical setting. It can, however, be useful in supporting patient histories and in the future it may be possible to use this data for clinical evidence.

This will require openness and collaboration between different industry players to ensure data compatibility; clinicians, ensuring practical utility; and regulators. Another possibility, perhaps with fewer barriers, is the curation of the vast amounts of data generated by connected consumer devices to form a database. A resource like this could be of enormous benefit to researchers and public health workers but would require a paradigm shift in industry regarding data ownership, as well as public buy in and debate around protection and fair use of potentially sensitive data.

The growth in sensor technology has interesting implications particularly for clinical engineering and rehabilitation, enabling richer data collection in controlled clinical settings and even enabling patients generate and record naturalistic data in real world settings. This may lead to more individualised devices or treatment protocols that suit patients' own daily lives, and also free up clinical contact time for value-added discussion with data collection and analysis performed remotely in between appointments.

IPEM members have recently undertaken important pieces of work into the regulation and best practice surrounding in-house manufacture medical devices and software as a medical device (SAMD)[35]. We want to continue this kind of work, ensuring participation of key stakeholders; access to necessary information; and effective dissemination so these documents are recognised and acknowledged where they can make an impact. We can do this by:

- **Fostering strong links and effective lines of communication with external organisations**
- **Scanning for indications of standards, policy and position reviews**
- **Strengthening reporting between IPEM's external representatives and internal committees**
- **Coordinating volunteer activity with office communications and engagement teams**

Digital twins, virtual replicas of real-world systems, are a good example of AI enabling a new research paradigm. They range from individual devices up to complex interconnected structures such as cities or natural landscapes. Using a combination of real-world or synthetic data and AI, a physics-based model can be generated to simulate testing and scenarios. This can be used to accelerate testing, reduce costs, and perform multiple destructive scenarios to thoroughly interrogate systems which may be impractical in the real world. The Climate Resilience Demonstrator (CReDo) is an example of a very large-scale project which connects digital twins across infrastructure and services, using connected data to build up a wealth of information around climate change and climate resilience[36,37]. At a smaller scale, digital twins may be used to model medical devices – as a prototyping tool to increase throughput and reduce material cost, or to examine the impact of design or procedural modifications on safety of performance. This may be a way of broadening participation in research and development by reducing barriers such as laboratory availability, high cost, and time available to spend conducting physical experiments.

Key topics to consider include:

— Digital transformation for all

- Exploiting opportunities to promote visibility through in-demand skills
- Supporting increased communication, cross-disciplinary conversation, and reduced siloing
- Identifying opportunities for improving performance, throughput, or efficiency through digital technologies and IoT

— Sharing best practice – fast troubleshooting; greater confidence

- Digital (i.e., AI, software, algorithm) development, assessment, QA, and deployment
- White papers – starting and leading discussions
- Modernising and expanding professional knowledge resources and dissemination methods
- Developing international links and outreach with under-resourced services with access to resources opportunity to engage with the wider community
- Developing professional knowledge management from source to dissemination

— Learning and skills development

- Peer-to-peer learning through a range of activities and resources
- Addressing skills, knowledge and familiarity needed for effective digital transformation in each discipline
- Cross-disciplinary discussions and working groups to bring together optimum skills mix for technology pathways.

Themes	Actions
NHS 'digital transformation'	Reviewing and modernising resource library
Resilience to infrastructure disruption and malicious activity	Exploring regulation, safety, effective management
Big data	Modernising and expanding data formats for professional knowledge dissemination (e.g., apps, plugins, media, databases and code)
AI and machine learning – robustness, safety, regulation	Exploring research, development and translation
Augmented, virtual, and extended reality (AR, VR, XR)	Engaging with technical, ethical, safety and regulatory developments in medical devices and equipment
Medical devices, SAMD and IOT	Focused cross-cutting events and fora for a joined-up technology pathway
Effective interfacing between clinical, scientific and infrastructural disciplines	

Personalised health

There has been some trend towards personalisation of healthcare for many years, with consumer apps and devices that help patients monitor and record health and wellness data. The pandemic was a force for change too, with increased interest in public and personal health, coupled with reduced access to healthcare for non-acute cases, driving growth in telemedicine. This requires people to embrace technology and to take ownership of their health data, whether that is for diagnosis, monitoring, or intervention. In the UK, NICE has identified a rise in innovative medicine categories, such as cell and gene therapies, as a key driver in scientific advances which must be embraced to deliver their vision for the future of medicine in the UK[38,39]. This will draw on genetic sequencing and analysis capabilities at individual and population scale to target both large public health challenges and rare but serious conditions.

At a population level, genetic data can reveal trends in disease incidence to help with risk assessment, targeted screening, and early intervention. At individual level, the increased speed and reduced cost of sequencing makes highly individualised assessment and decision making a possibility.

Collectively, this data has the potential to form a rich resource for research. However, effective safeguarding, security and ethical protocols are required to promote fair use and protect against exploitation[40]. While it will be easier to determine this at small, local levels, patient data is most powerful at scale where effects of various demographics are balanced out. If access can be negotiated with health care providers (clinical data) or industry (consumer devices), regulatory and ethical approval may provide further barriers. New databases are likely to be used for academic or industrial research first where data can be anonymised, and outcomes will not have a direct impact on patient pathways or clinical decision making.

Personalised health can only succeed at scale if data collection, analysis, interpretation, and subsequent implementation of learning are done in a standardised, harmonised way[41]. This is especially true looking at a population level because of the large number of variables. It will require close cooperation and understanding between developers, data generators (including patients themselves), analysts and those shaping and delivering clinical practice.

Lessons can be learned and inspiration sought from health systems with different approaches and attitudes. In China and Southeast Asia, digital technology is widely used in many aspects of daily life and app-based healthcare solutions already commonplace. In societies with predominantly local-acting privatised care, procurement can be quicker, allowing nimble procurement to assess new products and systems.

Imaging is inherently personalised and is predicted to be a growth area with the arrival of diagnostic hubs and emphasis on early detection and intervention, particularly for cancers. Personalisation can be achieved through a range of means including:

- **Intelligent use of imaging**
- **AI to learn about trends based on demographics**
- **AI to detect trends in patients' medical history**
- **Making health more accessible with community hubs and mobile scanners**
- **Increasing patient awareness and understanding through education and advocacy**
- **Big data analysis with -omics and imaging to optimise treatment plans**

Sensors and devices

Sensors and devices are particularly interesting for clinical engineering, rehabilitation, and biomechanics, where there is real opportunity to engage at any stage from idea to development to implementation using existing equipment or innovating in house. Small, robust, and wireless devices can be worn by patients in real world settings, capturing idiosyncrasies and building up an accurate picture of an individual patient's situation and needs. This has wide-ranging utility from gait analysis[42] to prosthesis fit and function[43]; vital signs monitoring including cardiac output[44] or neuronal activity; or even pattern recognition to help detect cognitive decline and alert to acute situations in dementia patients[45].

The ability to collect and analyse longitudinal field data can also shift the dynamic of clinical contact sessions. It can reduce time spent taking measurements and give more time for dialogue with patients and colleagues, creating or modifying devices and prostheses more quickly and precisely. Such an approach could increase the value and efficiency of contact sessions to staff and patients, making interactions positive experiences with overall improved outcomes. There are caveats regarding compliance, completeness, confidentiality, and accessibility of data between manufacturers and health providers, but this is an interesting area of research with good routes to clinical translation if effective regulatory and data frameworks are in place.

Software as a medical device (SAMD) could potentially update as often as the system that hosts it – iPhones can update every 6 weeks. Again, regulation and market vigilance must be nimble and ready to act to these timescales. Ownership and ethical and legal responsibility are also important areas to examine. A unified QA/QC approach and guidelines, together with practical toolkits, could support effective adoption across the country.

Case study 1

One of the major changes to outpatient services described in NHS England's Operational Planning Guidance for 2022 is the change to patient-initiated follow-up (PIFU)[46]. Follow-ups constitute two thirds of all hospital appointments – allowing patients to initiate follow-ups is intended to ensure those who need them are seen in an appropriate timeframe and making more efficient use of clinical time by increasing compliance and reducing no-shows.

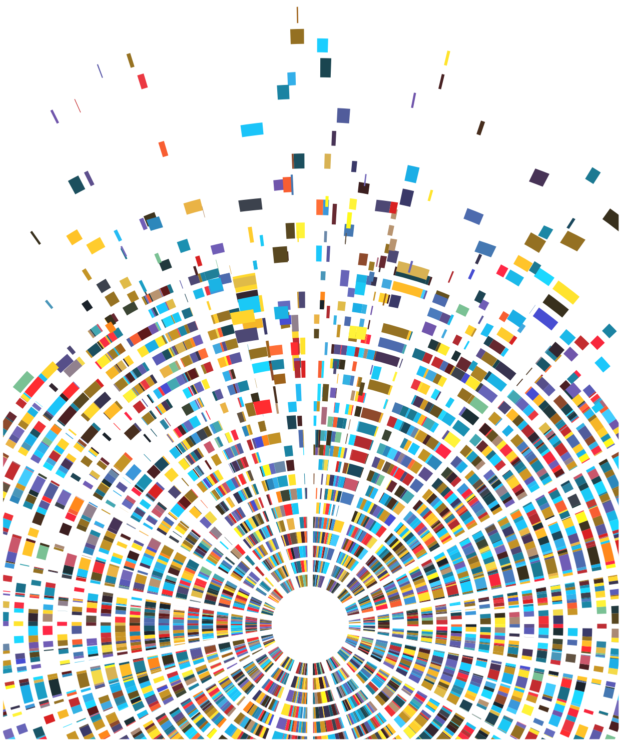
This can be seen as part of a larger movement towards giving patients greater ownership of their health and wellbeing, through the ability to gather and use data from consumer wearables and sensors, to providing the information and tools to make lifestyle choices rather than seek medical care. While this data may not be sufficiently robust or verifiable to make diagnoses or recommendations, the practice of recording regular observations should help focus decision making and lead to more focused, efficient contact time and improved compliance.

Genetic profiling

Technologies which enable detailed biological profiling of individuals at a molecular level have unlocked the potential of personalised medicine, but further developments are needed to make the vision a reality. Data collection and analysis must be integrated and dynamic to make ensure an accurate picture of a patient and their needs is captured.

Use of -omics and biomarkers can support personalised care by targeting treatments at genetic level and identifying more potentially successful interventions[47]. They can also be used in identification of at-risk patient groups to target priority screening groups, or make predictions on future disease likelihood[48,49].

-omics can combine with traditional modalities to give added richness to data. Imaging genomics correlate cellular genomics with tissue-scale imaging, while radiogenomics can be used to characterise tumour genotype and phenotype without biopsy. As well as being less invasive and more efficient, this kind of analysis captures sample heterogeneity in a way a biopsy may not[50].



Case study 2

As well as having utility in building up data banks and in screening programmes, genomics can be used to personalise treatments to increase efficacy with dose, agent, or regimen adjustments[51,52]. Imaging is inherently personalised, but the growth of data collection and compute capacity and the potential of -omics is opening avenues for more individualised diagnosis and treatment elsewhere in medicine. Genomic adjusted radiation dose (GARD) is an example of a method used to personalise radiotherapy by using a gene expression index to predict the clinical effect of therapeutic radiation in an individual[53]. Radiation oncology has traditionally assumed a uniform biological effect across patient cohorts. GARD may enable more tailored radiation regimes or lower doses, reducing toxicity to the patient.

The standard of care for determining physical radiation dose is the linear quadratic model, which gives an empirical relationship between ionising radiation dose and cell survival. Researchers from the Cleveland Clinic, Case Western Reserve University and Moffitt Cancer Centre in the USA previously developed and clinically validated a radiosensitivity index, a multigene expression index that estimates tumour radiosensitivity[54]. Integrating the radiosensitivity index into the linear quadratic model gives a quantifiable parameter of not just physical, but clinical effect of the prescribed radiation. This enables prediction of the therapeutic benefit to an individual patient. The model has been validated against datasets for breast cancer, glioblastoma, pancreatic cancer, and lung tumours.

'P4' medicine

A new approach to medicine, one that is preventative, predictive, personalised, and participatory, is being touted as something that can help address the global issue of noncommunicable diseases (including CVD, cancers, respiratory disease, and diabetes)[55]. Collectively, these represent the leading cause of death, disability, and reduced quality of life.

- **Preventative**
  - Education and engagement to encourage lifestyle change or other avoidance strategies
- **Predictive**
  - Dynamic data collection and effective communication
  - Efficient risk identification for early intervention
  - Enabling access to the right intervention at the right time
- **Personalised**
  - One of five major tenets of the NHS Long Term plan, defined as 'a new relationship between people, professionals and system'
  - Economically efficient management of serious long-term conditions
  - Using data and small-scale manufacturing to deliver individualised care
- **Participatory**
  - Requires action of patients and their support systems
  - People who invest in health monitoring will contribute more to population data
  - This can be used to tailor their own care (personalised), identify early symptoms (predictive), or prompt lifestyle changes or prophylactic treatment (preventative).

Key topics to consider include:

- **Increased clinical, public (e.g., Biobank) and consumer data generation**
  - Big data analysis
  - Compilation of both large and smaller-scale, project-focused databases
  - Ethics, security, and fair use
- **'P4' (preventative, predictive, personalised and participatory) medicine**
  - Patient engagement – increasing accessibility and understanding
  - Intelligent data analysis
  - Diagnostic hubs
    - Workforce advocacy and safe staffing
    - Imaging, training and efficiency technologies
    - Skills and technologies for rapid, accurate, early-stage detection and diagnosis
    - AI for risk detection, targeted screening and early intervention
- **Modernising traditional physics and engineering in medicine**
  - Designing with *NHS Digital* and *Greener* transformation strategies in mind
  - Patients as active, engaged users
    - Accessible, understandable information
    - Effective and efficient information transfer
  - Combining new technologies on traditional platforms
    - E.g., Radiogenomics for biopsy-free tumour genotyping and phenotyping.

Case study 3

Researchers at the breast cancer research lab at the University of Utah developed lab-grown organoids and murine xenografts from samples isolated from living cancer patients. They used the *ex vivo* models to trial a panel of 45 drugs – including approved and experimental treatments – to determine which might work best for each patient[56]. Trialing drugs in patients would be impractical, highly toxic, and potentially breed drug resistance in the individual. The model tumours were found to match the original in growth rate, active genes, and pharmacological response.

This approach, **functional precision medicine**, has the potential to screen multiple treatment options with high throughput and low risk to the patient. It is also a potential route to expanding approved use cases, or obtaining special ethical approval on an individual basis. As it is driven by tangible observed results, the success rate is higher than that obtained by genome sequencing of cancerous tissue – while this can identify mutations, it cannot necessarily identify an appropriate treatment. One study reported that only 0.4% of patients were matched with FDA-approved drugs, or 9.6% with an expanded set of therapies for targetable gene alterations following whole exome sequencing (based on a cohort of 769 patients)[57]. An unrelated trial on metastatic breast cancer had 46% of the cohort with potentially targetable gene alterations. However, there was no significant difference to the treatment time for matched patients compared to those without genetically matched therapies.

A significant difference between the cancer patient and the organoid and xenograft models is the lack of immune system, which is not current reproducible in *ex vivo* systems. The trial was unable to prevent fatal recurrence but did demonstrate increase progression-free survival and time to next systemic therapy, indicating an interesting proof of concept.

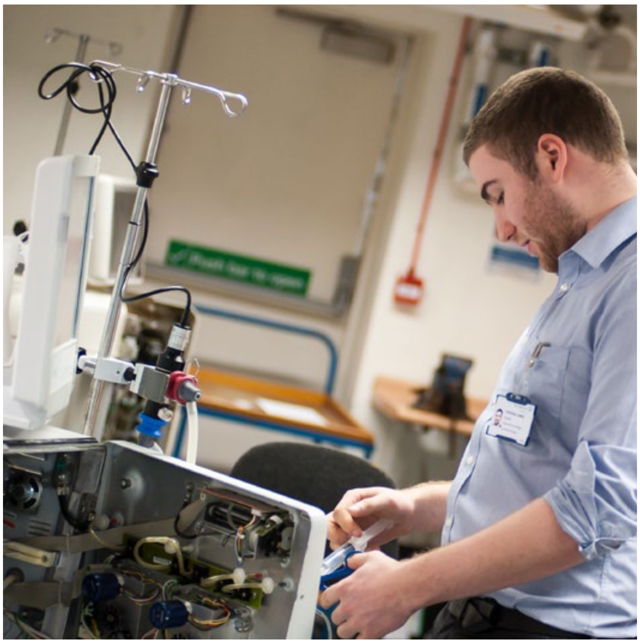
Themes	Actions
Wearables, sensors and consumer devices	Safe and fair access to data
-omics	Expanding professional knowledge curation to include data bases
Data-driven decision making	Modernise education and training tools
'Patient-centred' or 'patient-led' health	Collecting and collating repositories of relevant news and scientific publications to support internal work streams
Predictive, preventative, personalised, participatory medicine	Identifying opportunities to map physics and engineering to broader trends in medicine
Advances in imaging – sensitivity, specificity, resolution	Examining regulation and best practice, especially where dynamic updating or highly individualised delivery or response may apply
Technologies and strategies for reducing effective dosing	

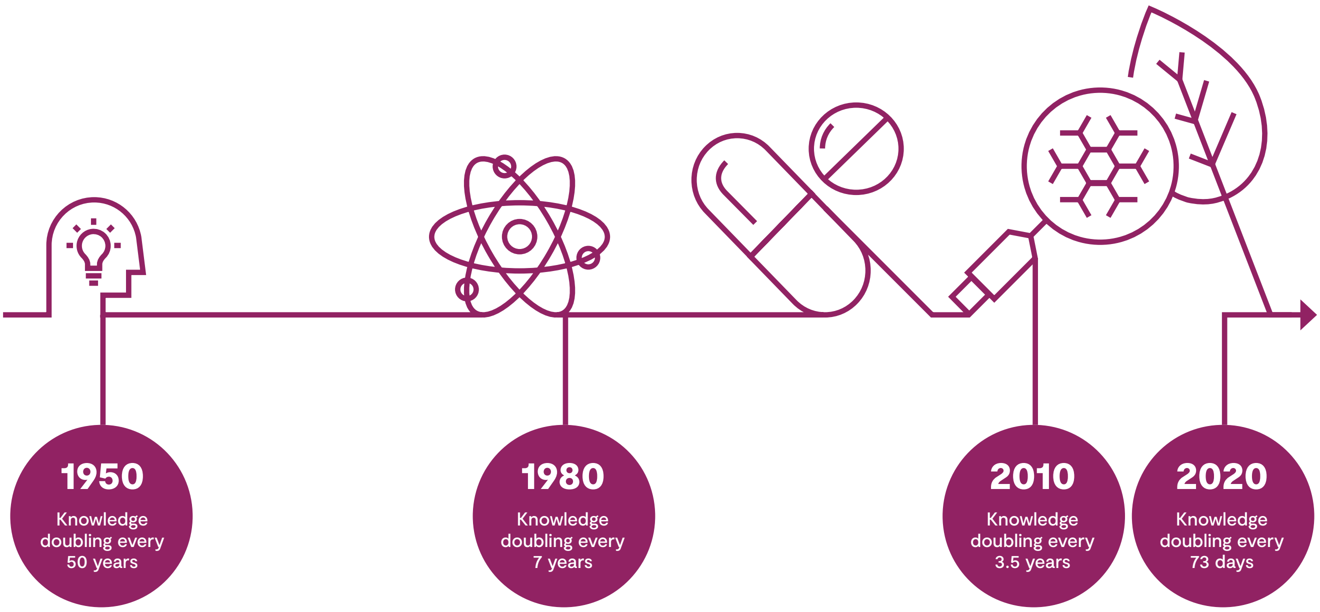
5

Methods and implementation

How we went about it

IPEM has engaged extensively to develop an analysis of the factors shaping our future operating environment. This included discussion with IPEM members from a range of different disciplines and sectors, horizon scanning activities and literature surveys. It is purposely aligned with those from other organisations, such as the NHS, UK government, UKRI, EPSRC, IET and others, but is focused on the role that healthcare scientists play in the health and care system of the future, and the assurances and resources that will be required to achieve this.





Scientific, technological, and medical knowledge is expanding exponentially. In 1950, the doubling time of medical knowledge was estimated at 50 years; in 1980, 7 years; 3.5 years in 2010 and 73 days by 2020[58,59].

The strategy is envisioned as a living, agile framework, personalisable to each specialism and supporting collaboration.

It will adapt to respond to areas of interest and unexpected surprises but will provide the guidance to steer as a cohesive unit.

It will help us shape the in-house policies and practices to get innovative ideas off the ground.

Image courtesy of the Big Bang Fair 2018

	How can IPEM support innovation?
Workforce and financial pressures	• Developing professional knowledge to share best practice, research and current opinions across membership and beyond • Identifying areas of demand for resources (events, articles, reports, etc.) • Developing resources to support professional development • Reviewing prizes, awards and bursaries portfolio to ensure they best meet the needs of members and advance the professions IPEM represents
Inaction	• Identifying important risks, opportunities and activities • Coordinating and supporting appropriate groups in advance • Communicating through appropriate channels to signal intent and avoid duplication • Use office and council support to enable groups to achieve greater impact
Poor communication	• Reducing bureaucracy with clear lines of connection and communication • Ensuring reporting between councils and other volunteer groups • Giving opportunities for all members to engage and feed back • Developing and maintaining key external relationships

Implementation

Horizon scanning across journal papers, conferences, meetings, policy, and regulatory announcements will be led and curated within the IPEM office. We will actively encourage and welcome contributions from across the member network, as this will increase the scope and richness of the data we gather.

This approach will give IPEM's Science, Technology & Engineering Research and Innovation Council (STERIC) oversight of current activity and likely future trajectories, enabling intelligent and strategic management. STERIC will lead implementation of the strategy within IPEM and ensure it is reflected in our working practices and professional knowledge outputs. We will work to ensure that there is clear, open, and constructive dialogue between STERIC and other committees and groups to ensure that activity is accessible to the whole member community, with ideas and cooperation welcomed.

Special Interest Groups (SIGs) will be key to driving the top-level strategy into relevant, informative, and engaging outputs. Initially, strategic direction and prioritisation will be led by STERIC who will in turn identify SIGs and appropriate communities of interest.

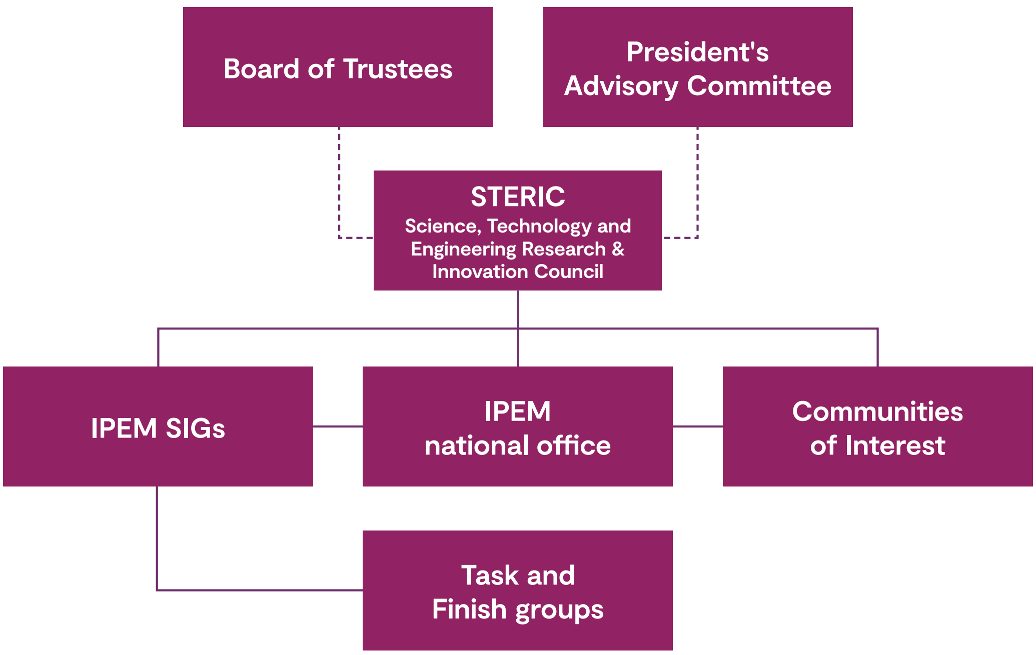
Over time this should evolve into a two-way relationship, with a flow of ideas across the organisation and with STERIC acting as the nexus and reporting body. The SIGs will also

act as conduits from wider membership into coordinated activity at planning and delivery levels. We will work to ensure SIGs and STERIC are supported in building and maintaining strong, open working relationships.

Futures thinking should be embedded into the culture throughout IPEM's membership. This will be a gradual process, starting with top-level governance so that it is reflected in organisational planning and delivery of all IPEM activity, both internal and external. Futures thinking and future science can feed into IPEM's extensive events calendar to create opportunities to bring together diverse experience, expertise, and opinion.

Some of this change will require training while some will come from reflective learning and conversation. It will take time to acquire before becoming embedded, but futures thinking encourages creative, adaptive thinking and a critical problem-solving approach that will be important in establishing IPEM's place in a time of transformation across healthcare research and delivery.

The strategy will not just affect internal practices but also shape the way we present to and interact with key stakeholders and the general public. We will use the strategy as a foothold to mark our position and project our strengths today as well as their future value. This framework and united trajectory will help us send a clear message about our vision and values to partner organisations, policy makers and employers. This is essential in growing our visibility and reputation and creating a solid platform from which to move forward. With a rapidly shifting political and technological landscape, it is vital that we ensure healthcare scientists, engineers and technologists have a place at the table in shaping the future – whether this is through management, research and development, or translation and adoption of new technologies or work practices.



Strategy delivery, led by STERIC, will link through all levels of IPEM. There will be opportunities to engage through various short- or longer-term roles.

This strategy reflects our values, and will help us to build in new opportunities for meaningful and effective collaboration across our richest resource, our member and volunteer network:

Trusted
To maintain the trust of members and stakeholders, IPEM must look forward to ensure we are representing our members effectively in an ever-changing workplace environment and scientific landscape. We will horizon scan frontiers in science, technology, and engineering from research to clinical use, making use of the breadth of expertise in our membership. We will continue to champion healthcare science roles and their critical importance as the NHS seeks to transform diagnostic imaging and cancer services.

Inclusive
The strategy is for all members, regardless of career stage or discipline. It is a framework whose success will depend on the engagement and enthusiasm of members, particularly in emerging and cross-disciplinary spaces.

Progressive
Healthcare is changing, with the adoption of new technologies; integration of genomics; and emphasis on patient-centred care. We will embrace these changes and reassert the importance of engineering and physics in medicine as the critical element in translating scientific discovery into tangible improvements in quality of life.

5

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