technopolis group

May 2024

Evaluation of the EPSRC Healthcare Technologies IRC

Final Report

www.technopolis-group.com

May 2024

Evaluation of the EPSRC Healthcare Technologies IRC

Final Report

Peter Varnai, Bruno Raabe, Maike Rentel, Rebecca Babb, Adebisi Adewusi, Nadya Mihaylova

Table of Contents

Tables

Figures

Boxes

Executive summary

Interdisciplinary Research Collaborations (IRCs) are networks of excellence aimed at attracting and building critical mass and breaking siloes across engineering, physical, and biomedical sciences. The Engineering and Physical Sciences Research Council (EPSRC) has played a key role in funding IRCs in areas of key future industrial relevance to the UK, including in healthcare technologies.

Overall, the Healthcare Technologies IRC funding represents a total investment of £59.1 million between 2013 and 2023. EPSRC funded three IRCs in sensing systems for healthcare in 2013 and renewed these in 2018. Additionally, it funded a fourth IRC in targeted therapeutic delivery in 2018. EPSRC also funded four Next Step Plus projects through a competitive process. The aim of these IRCs was to deliver preclinical and precompetitive projects, from basic applied research to early proof-of-concept projects, with potential for impact in health. The goal is to enable people to live healthier lives and to make an impact in future industrial areas for the UK.

The specific IRCs and related projects include:

IRC i-sense: Early-Warning Sensing Systems for Infectious Diseases; and Next Step Plus projects u-sense: Ultra-Sensitive Enhanced NanoSensing of Anti-Microbial Resistance; Smartphone mRNA: Smartphone Powered mRNA Sequence Detector.

IRC Proteus: Multiplexed 'Touch and Tell' Optical Molecular Sensing and Imaging; and Next Step Plus project Photonic Pathogen Theranostics: Point-of-care image guided photonic therapy of bacterial and fungal infection.

IRC SPHERE: Sensor Platform for HEalthcare in a Residential Environment; and Next Step Plus project OPERA: Opportunistic Passive Radar for Non-Cooperative Contextual Sensing.

IRC TeDDy: Targeted Delivery for Hard-to-Treat Cancers.

EPSRC commissioned Technopolis Limited to conduct an independent evaluation of its investment in Healthcare Technologies IRCs. The aim of the evaluation was to assess the outcomes and early indicators of impacts of the IRC programme and provide evidence of the advancements in knowledge generation, economic impact and societal benefits through a series of in-depth case studies. Additionally, the evaluation aimed to assess the programme's design, implementation and management. The evaluation was carried out between April 2023 and March 2024.

Methodology

The evaluation followed a theory-based, mixed methods approach, building on a logic model and an evaluation framework. Analysis of documents and monitoring data was complemented with data from stakeholder consultations. Quantitative data, where available, was combined with qualitative information to provide robust evidence and develop recommendations for EPSRC and the research community.

Secondary data analysis involved a portfolio analysis of the funded projects using data from Researchfish submissions by research leads and Dimensions data from Digital Science. Additionally, we conducted an online survey with all participants from the four IRCs, including academic research leads and co-investigators, industry partners, NHS hospital trusts and third-sector participants. We conducted a programme of in-depth interviews to further our understanding of the nature and scale of the specific outcomes and impacts of the programme to develop case studies.

As with any evaluation, there were limitations that prevented the observation and aggregation of the full extent of project outcomes and impacts. This was partly due to the timing of the evaluation and partly due to the limited availability of comparable data in monitoring datasets and from interviews.

Results

The 10-year IRC programme has recently completed, and while many benefits will emerge in the coming years, the programme has already demonstrated success in achieving its stated objectives (detailed below) and has created important results and early impacts.

Creating new knowledge. IRC research projects have generated a wealth of new knowledge manifested in many different forms, including academic peer-reviewed publications, conference presentations, new research tools, methods and models, specialised knowhow and protected intellectual property. The IRC funding to UK researchers has enabled internationally leading, highly cited publications, among other types of research outputs. Over the 10 years, the IRC generated 683 publications, 30 new databases and datasets, 15 research tools and methods, 11 distinct software and technical products, and 11 intellectual property rights. These quantitative figures indicate the intensity of knowledge generation activities, while case studies provide evidence of the quality of these research outputs and outcomes.

Building critical mass. The scale of IRC investment enabled the attraction of exceptional talent to lead and collaborate in healthcare technologies across disciplines involving engineering and physical sciences. It has built unique capacity for the future by training over 150 early- and mid-career researchers through various skills and career development activities and creating a network of 110 established researchers in the UK. The convergence of expertise at this scale around shared interests, goals and vision has enabled the development of new sensing technologies and drug delivery systems for cancer. This progress was made possible by institutional support and existing infrastructure at collaborating partner organisations. It is likely that a much larger number of researchers will benefit from the programme in the future through the multiplier effect of upskilled and established IRC researchers.

Developing partnerships. The IRC programme created an initial network of 30 organisations in the first funding period (2013-2018) and expanded it to 73 organisations, now including IRC TeDDy, in the second funding period (2018-2024). A Partnership Resource Fund was established within IRC grants, which was particularly useful in bringing new UK partners into the collaboration and initiating new joint research activities. Over half of these organisations were UK universities and research institutes. The partnerships also brought skills and expertise from industry and included the perspectives of end-users (clinicians and patients) and policy makers. An analysis of IRC co-publication data pointed to limited direct involvement in research of industry, government and health facilities. However, it indicated the IRC's international leadership in healthcare technologies, with a third of its publications featuring with international authors.

Enabling translation to products and practices. The IRC programme was particularly successful in developing and progressing technologies of healthcare relevance due to its interdisciplinary research excellence, which helped to tackle large scale and complex challenges. The case studies developed through the evaluation illustrate the breadth and depth of these innovations and inventions. Patents have been filed, spinout companies have been created and investments have been raised on the back of these technological advances. These cover sensing systems for prediction of infectious disease dynamics, new diagnostic technologies for the clinical environment and resource-limited settings, and multi-sensor technology for monitoring disease symptoms in daily life. Targeted drug delivery using various innovative approaches have also advanced, although integrating these into a synergistic system was not viable. The IRC programme was also able to progress specific technologies beyond Technology Readiness Level (TRL) 3 and apply them in fields extending beyond healthcare.

Informing the research landscape. IRC directors and co-investigators were members of key committees, contributing to high-level discussions, shaping policies and the national research landscape. These include topics such as information governance across the health and care system, deployment of digital healthcare technologies across the NHS, and the importance of long-term investment in engineering and physical sciences. The three original IRCs shared knowledge at an 'all IRC conference' in Bath in 2017, and IRC directors were members of each other's mid-term review boards.

Achieving sustainability. The achievements of the IRC programme are expected to be sustained and grown over time through securing additional funding from a mix of public and private sources. This will ensure that these virtual 'national centres of excellence' will become self-sustaining, allowing partnerships to continue collaborating on tackling new challenges. The evaluation has shown that the four IRCs have already raised a total sum of over £150 million from public and private funding sources for follow-on research and development projects, which is 2.5 times the overall IRC investment. A portion of this additional funding is specifically provided by funders and investors to create and grow the six spinout companies from the IRCs, further exploiting the technologies developed in the IRCs. Another role for this leveraged funding is to create new EPSRC Centres for Doctoral Training at the interface of health sciences and engineering, sharing the knowledge and tools developed by the IRCs, and creating interdisciplinary skills supply for improved R&D capacity in the UK.

Recommendations

To maximise the future impact of similar large-scale research programmes, the following points and actions may be considered by EPSRC.

1. Improve the potential for translational impact

1.a Explore and better understand the role industry can play in TRL1-3 research. Currently, a low level of industry engagement was visible in this evaluation. It may be unfeasible for large multinationals to extract value from early-stage, proof-of-concept research. A larger Partnership Resource Fund could enable companies to collaborate on high-risk joint research projects.

1.b Explore further funding options for researchers to help them to progress their technologies towards deployable solutions beyond project end. This may involve advocating for investment more widely into healthcare technologies as a 'joint programming initiative' and convening interested (public and private) funders to this end. For example, very few trials appeared to test the safety and efficacy of technologies developed by IRCs. Potential co-funders may include the NIHR, Wellcome and Cancer Research UK.

1.c Link IRC spinouts to dedicated funding agency support. Spinouts that receive funding from the British Business Bank and Innovate UK are more likely to succeed. These spinouts also received higher levels of private 'follow-on' equity capital. Nurturing spinouts in the UK will help reduce the negative impact of research outputs taken abroad for commercialisation. Taking an active role in connecting IRC spinouts to seed funding via the UK Innovation and Science Seed Fund may also be considered.

1.d Link research projects with the UK Catapult network, which provide support to both academia and businesses in bringing research to market more quickly. They offer specialist programmes to upskill researchers, provide specialist infrastructure, testbed and demonstration environments, among other resources. However, healthcare technologies may not have a 'natural home' among the current Catapult Centres.

2. Embed the programme better in the training & international research landscape

2.a Encourage researchers to connect better with world leaders in their thematic areas of interest. Mobility Fellowships have demonstrated how UK researchers benefit from visiting international organisations to enhance research excellence. This can also contribute to growing the UK's global leadership in healthcare technologies while recognising the need to protect UK intellectual property.

2.b Encourage researchers in funding calls to connect with relevant Centres of Doctoral Training and support nurturing new talents as part of the drive to create improved R&D capacity in the UK. This is particularly timely as EPSRC is investing in training over 4,000 doctoral students over nine years in critical technologies.

3. Improve the monitoring practices

3.a Develop a core set of common indicators for large-scale programmes, such as the IRCs, through inclusive stakeholder workshops, and link these to expected research outcomes across all objectives. Projects should record and collect such monitoring data and provide it annually to EPSRC. Improved monitoring practices would not only support future evaluations but also provide ongoing formative learning opportunities for project leads. It is important that the IRC management teams retain flexibility to manage such large-scale investments while adhering to robust monitoring and accountability mechanisms. It is suggested that large-scale investments have agreed, clearly defined, time-bound milestones to help achieve project objectives, and that associated metrics are in place to track progress. Reviewing these milestones could help to make efficient funding decisions for research strands within large-scale projects.

Preamble

The Engineering and Physical Sciences Research Council (EPSRC) commissioned Technopolis Limited to conduct an independent evaluation of EPSRC's investment into Healthcare Technologies Interdisciplinary Research Collaborations (IRCs). The aim of the evaluation was to assess the intended (and unintended) outcomes and early impacts of the IRC programme and provide evidence of the advancement in knowledge generation, economic impact and societal benefits through a series of in-depth case studies. The evaluation was carried out between April 2023 and March 2024. The is the final report of the evaluation, and it provides context to the IRC programme, describes the methodology and limitations of the evaluation, discusses results and their implications, and develops recommendations for EPSRC and the broader research funding community. Two separate documents accompany this report: a compendium of case studies and appendices with detailed analysis of the data collected.

1 Introduction

1.1 Background to EPSRC's contribution to interdisciplinary research in healthcare technologies

Interdisciplinary research collaborations (IRCs) are networks of excellence aimed at attracting and building critical mass and breaking siloes across engineering, physical and biomedical sciences, by integrating techniques, methods, data, theories and concepts from two or more domains of knowledge. These large-scale funded projects, led by academic principal investigators, operated in collaboration with other university departments, industrial partners, healthcare professionals, non-profit organisations, government agencies and others. As such, IRCs play a vital role in pooling the expertise and resources required to translate basic research into technologies relevant to address complex societal challenges.

Since its inception in 1994, the Engineering and Physical Sciences Research Council has played a key role in funding IRCs in areas of key future industrial relevance to the UK. Early IRCs covered domains of Tissue Engineering (funded by EPSRC, BBSRC, MRC between 2001-2007)[1], and (Bio-)Nanotechnology (funded by EPSRC, BBSRC, MRC and MoD between 2002-2009)[2,3]. The current study is looking at IRCs in Healthcare Technologies.

Translational research in healthcare technologies

Translational research advances basic research and early-stage proof of concepts from laboratory to a mature technology demonstrated in real life conditions, where these can be further developed by industry, bridging the gap between basic research and marketable products. Public investment in translational research can de-risk this complex process and has become an important proposition for research funders to deliver impact. Many public and philanthropic funders are stepping in to bridge the funding gap known as the 'valley of death' between a proof of concept and validating business models and value propositions to

[1] https://gow.bbsrc.ukri.org/grants/AwardDetails.aspx?FundingReference=TIE13617

[2] https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=GR/R45659/01 and https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=GR/R45680/01

[3] Memorandum from the Research Councils UK, Written Evidence to the Select Committee on Science and Technology https://publications.parliament.uk/pa/cm200304/cmselect/cmsctech/56/56we05.htm

commercialise a technology. Measuring the progress along the development pathway for new technologies can be described in terms of technology readiness levels (TRLs)[4].

ESPRC's approach to and support for health technologies

Healthcare technologies is one of 10 themes within the EPSRC grant portfolio[5], which includes engineering, mathematical and physical sciences, quantum technologies, research infrastructure, manufacturing the future, information & communication technologies, energy & decarbonisation and digital economy. The healthcare technologies theme is underpinned by the EPSRC Health Technologies Strategy 2023[6], which aligns with the mission-driven priority of 'Transforming Health and Healthcare' of EPSRC strategic delivery plan 2022-25[7], wider UK Research and Innovation themes (for example, ageing, wellbeing and tackling infections) and the NHS Long Term Plan[8]. The healthcare technologies theme supports research across disciplines, with the aim of accelerating translational research with potential for impact in health and to enable people to live healthier lives.

Stakeholder engagement forms a cornerstone of EPSRC's approach to research[9]. EPSRC's Health Technologies Strategy 2023 was developed through a 12-month community consultation process to identify health challenges which the engineering and physical sciences may help to address[10].

Three challenges were identified with associated priorities, as outlined in Table 1.

Table 1 EPSRC Healthcare technology strategy challenges and linked priorities

Challenges	Priorities
1. Improving population health and prevention of ill health	Population models to support communities and health professionals
	Predictive approaches to a healthy society
	Engineering healthier environments
2. Transforming early prediction and diagnosis	Tools to advance earlier diagnosis and detection of disease
	Novel techniques for patient specific diagnosis
	Detecting infections and antimicrobial resistance
	Supporting people to manage their own health
3. Discovering and accelerating the development of new interventions	Resilient Manufacturing
	Therapies for chronic conditions

[4] Activities associated with different technology readiness levels (UKRI, 2022) Available at: https://www.ukri.org/publications/activities-associated-with-different-technology-readiness-levels

[5] https://www.ukri.org/councils/epsrc/remit-programmes-and-priorities/our-research-portfolio-and-priorities

[6] https://www.ukri.org/wp-content/uploads/2023/03/EPSRC-23032023-health-technologies-strategy-Final.pdf

[7] https://www.ukri.org/publications/epsrc-strategic-delivery-plan/epsrc-strategic-delivery-plan-2022-to-2025/

[8] https://www.longtermplan.nhs.uk

[9] https://www.ukri.org/councils/epsrc/guidance-for-applicants/what-to-include-in-your-proposal/health-technologies-impact-and-translation-toolkit/stakeholder-engagement/

[10] https://www.ukri.org/publications/epsrc-health-technologies-strategy/epsrc-health-technologies-strategy/

	Engineering and materials research with therapeutic properties
	Innovative technologies for physical intervention

In addition to the above challenges and priorities, the strategy sets out six enablers that research within health technologies should address: (1) Responsible approaches to data, to ensure health data rights are respected; (2) Patient and public involvement and engagement to ensure future users inform research; (3) Sustainable healthcare and health systems to reduce healthcare's impact on the environment and deliver healthcare more affordably and resiliently; (4) Improving translation readiness through support to researchers; (5) Reducing health inequalities in the UK; (6) Supporting knowledge and skills in health technologies through investment careers and training.

The identified healthcare challenges, priorities and enablers in the strategy respond to the NHS Long term Plan and provide the basis to addressing current health problems and transforming future health. It builds on previous strategies and aligns with the EPSRC strategic delivery plan 2022-25 to build critical mass in healthcare technologies through investments in institutes, hubs and partnerships. The healthcare technologies theme thus seeks to fund interdisciplinary and cross-sectoral basic and applied research (TRL 1 to 3)[11] with potential for translation that can eventually lead to large-scale socio-economic impacts in the UK. It also seeks to promote cross-council research, such as UK Regenerative Medicine and accelerate translational research through partnerships with funders such as Wellcome, Cancer Research UK and the National Institute for Health and Care Research[12].

1.2 Healthcare Technologies IRC programme

In 2013, EPSRC funded three IRCs in sensing systems for healthcare. Further funding calls followed in 2017 to support the IRCs and new avenues of related research and engagement with new partners (IRC Next Step Plus initiatives). In 2018, an additional funding call was launched for an additional IRC in targeted therapeutic delivery. Table 2 below provides a summary of the IRC programme objectives by funding period/value, area, and expected outcomes.

Table 2 Healthcare Technologies IRC programme objectives, areas, and outcomes

Funding period	Funding value	Programme objectives	Area	Expected outcomes
2013-2018	£32.2m	To build critical mass around UK research strengths in engineering and physical sciences that underpin healthcare	Sensing systems for prediction, diagnosis and monitoring in healthcare	Novel technological platforms for disease(s) or for monitoring environmental factors that impact on health
		To maximise industrial and end-user involvement and increase translation to products/practices		
		To bring in new UK research partners during the grant (industry, clinicians, policy makers), to complement and strengthen the expertise		

[11] https://www.ukri.org/wp-content/uploads/2022/01/EPSRC-11012022-theroleofdifferentfundersinthehealthcaretrllandscape.pdf

[12] https://www.ukri.org/what-we-do/supporting-collaboration/supporting-collaboration-epsrc/strategic-partnerships/

2018-2023/24	£16.7m	To support the three existing IRCs to ensure they become self-sustaining national centres of excellence		
		To support new avenues of related research that were not part of the original IRC (Next Step Plus Initiatives)		
		To bring in new partners that were not funded through the original collaboration		
	£10.3m	To address challenges of developing technologies for targeted delivery of medicines, from nanomedicines to large molecules	Technologies to transform targeted therapeutic delivery	Design of novel formulations and new drug vehicles, manufacturing of medicines and characterisation of therapies
		To create interdisciplinary collaborations to bring together world leading research expertise		

Source: Technopolis analysis of programme documentation and grant information from UKRI Gateway to publicly funded research and innovation (GtR).

1.3 Overview of funded IRCs

In total, four 'core' IRCs and four Next Step Plus projects were funded through a competitive process. Overall, this represented 11 grants and a total investment of £59.1 million from 2013 to 2023, with a few projects completing in 2024. Three core IRCs received £13 million to £15 million each through two consecutive grants in the 10-year period, while the fourth one started in 2018 and received one grant of £10 million over six years. Similar to earlier IRCs, these collaborations were led and co-led by academic investigators and supported by project partners such as businesses, NHS hospitals, government agencies and research institutes. The aim of these IRCs was to deliver preclinical and precompetitive projects, from basic applied research to early proof of concept projects that can make real impact in future industrial areas for the UK. Note that IRC funding was not available to support PhD studentships or conducting clinical trials. The four Next Step Plus projects (each with a grant of £1 million to £1.4 million) were designed to support new specific research related to the original three core IRCs but not funded through existing collaboration.

In the following we introduce each IRC and related Next Step Plus projects.

1.3.1 IRCs in sensing system for prediction, diagnosis, and monitoring in healthcare

IRC i-sense: Early-Warning Sensing Systems for Infectious Diseases (2013 to 2023/24)[13]

IRC i-sense set out in 2013 to develop low cost early-warning sensing systems to support diagnoses, monitoring and prevention of infectious diseases. The aim was to develop technologies that provide real-time monitoring of infections, such as symptoms reported online and mobile diagnostic tests, to be used in GP surgeries, community settings and developing countries. In 2017, the IRC received follow-on funding to retain key members of the IRC team and maximise impacts from the original grant to engineer 'agile' early warning sensing systems to adapt to emerging and re-emerging infectious diseases and anti-microbial resistance. Two related Next Step Plus projects were also funded:

[13] https://gtr.ukri.org/projects?ref=EP%2FK031953%2F1 and https://gtr.ukri.org/projects?ref=EP/R00529X/1

- **u-sense (2018-2024):** Ultra-Sensitive Enhanced NanoSensing of Anti-Microbial Resistance.[14]
- **Smartphone mRNA (2018-2023)**: Smartphone Powered mRNA Sequence Detector[15]

IRC Proteus: Multiplexed 'Touch and Tell' Optical Molecular Sensing and Imaging (2013 to 2023)[16]
IRC Proteus set out in 2013 to deliver a transformative 'point-of-care' immediate sensing device to help doctors in intensive care units (ICU) to make rapid and accurate diagnoses that would inform therapy and ensure patients get the right treatment at the right time. From 2017, with the support of follow-on funding, Proteus aimed to accelerate the pathways to take new technologies into patients, namely a fibre-based optical medical imaging device and fluorescent probe reagents for diagnostics. In addition, the project sought to explore commercial opportunities from the technologies developed. One Next Step Plus project was funded in association with Proteus:

- **Photonic Pathogen Theranostics (2019-2023)**: Point-of-care image guided photonic therapy of bacterial and fungal infection.[17]

IRC SPHERE: Sensor Platform for HEalthcare in a Residential Environment (2013 to 2023)[18]
IRC SPHERE set out in 2013 to create a platform of healthcare sensor systems capable of employing video and motion analytics to improve health in home setting. The aim was to use data-fusion and pattern recognition through a common platform of sensors to help with prediction of falls, detection of strokes, eating behaviours, periods of depression, and others. From 2017, SPHERE aimed to test the system with over 200 individuals and accelerate testing in real patient applications via the NHS. One Next Step Plus project was funded in association with SPHERE:

- **OPERA (2019-2023)**: Opportunistic Passive Radar for Non-Cooperative Contextual Sensing.[19]

1.3.2 IRC in technologies to transform targeted therapeutic delivery

IRC TeDDy: Targeted Delivery for Hard-to-Treat Cancers (2018-2024)[20]
IRC TeDDy set out in 2018 to develop multimodal delivery systems for a range of therapeutic agents to reach target sites in the context of hard-to-treat cancers and reduce side effects of chemotherapy treatments. The researchers aimed to combine several approaches for this purpose, including high-capacity nanoparticle carriers (including metal organic frameworks and organic cages), implantable devices (such as electrophoretic ion pump) and injectable hydrogels. The IRC sought to follow a holistic approach of validation from the conception of

---

[14] https://gtr.ukri.org/projects?ref=EP/R018391/1
[15] https://gtr.ukri.org/projects?ref=EP/R018707/1
[16] https://gtr.ukri.org/projects?ref=EP/K03197X/1 and https://gtr.ukri.org/projects?ref=EP/R005257/1
[17] https://gtr.ukri.org/projects?ref=EP/R018669/1
[18] https://gtr.ukri.org/projects?ref=EP/K031910/1 and https://gtr.ukri.org/projects?ref=EP/R005273/1
[19] https://gtr.ukri.org/projects?ref=EP/R018677/1
[20] https://gtr.ukri.org/projects?ref=EP/S009000/1

the delivery system in the laboratory to its real-world clinical application. To optimise this path and maintain bioavailability of the active therapeutic agent, the IRC would also conduct delivery and manufacturing research related to device fabrication and develop a novel industrially relevant modelling tool. The new technologies aim to deliver drugs effectively for the treatment of three hard-to-treat cancers in the brain (glioblastoma), lung (mesothelioma) and pancreatic cancer.

1.4 Evaluation objectives

The main objective of the evaluation, as requested in the specifications, was to conduct a detailed impact evaluation of the EPSRC Healthcare Technologies IRC programme from its inception to-date. In particular, it aimed to:

1. Critically review the value and impact of IRC investments and the extent to which the benefits sought have been achieved.
2. Assess the intended/unintended outcomes and early impacts resulting from the investments.
3. Assess the early indicators of economic impacts of the programme, including return on investment.[21]
4. Provide a light touch process evaluation of the programme.

Impact-related questions guiding the evaluation were formulated to identify how the IRC programme's outputs and outcomes have led, or will lead to impact on research knowledge, people & skills, the UK economy, and on society.

- To what extent has the programme created new knowledge that has been valuable in driving impact in real life situations?
- To what extent has the programme provided opportunities for interdisciplinary training and skill development to address skills gaps and national needs and build critical mass?
- To what extent has the programme created new networks and developed partnerships with businesses, clinicians, policy makers and others?
- To what extent has the programme created a vision for a national research landscape and established/contributed to the UK's leadership in disruptive sensing systems for healthcare and targeted therapeutic delivery?
- To what extent has the programme contributed to growth of new businesses, leveraged additional funding and achieved return on investment?
- To what extent has the programme been successful in creating impacts for health and society?
- To what extent has the funding enabled the IRCs to become self-sustaining in the future?

Process-related evaluation covered strengths and weaknesses of the programme design, implementation and management.

[21] EPSRC funds early phase research and technology development that broadly covers technology readiness levels TRL1-3. While it is too early for these activities to provide direct economic impact, some technologies (e.g. digital) may progress through the TRL scale faster to products and solutions that can have direct economic impact, especially technologies that emerge from IRCs that had a lifespan of 10 years. It is clear that the evaluation can only provide an early indication of the total future economic impacts stemming from EPSRC IRC investment.

1.5 This report

This impact and process evaluation has focused on assessing EPSRC's Healthcare Technologies IRC programme as a whole. The analyses of data from individual IRCs should not be used for comparison of their relative performance. This report presents the evaluation results based on data collected between April 2023 and December 2023.

Section 2 provides a description of the IRC programme's logic model and an overview of the methodology used in the evaluation. Section 3 presents the results and discusses the outcomes and early impacts in the areas of Research, Skills, Society, Economy; along with a process evaluation of the IRC programme's design and implementation. Section 4 offers conclusions and recommendations based on the evaluation findings.

2 Methodology

A theory-based evaluation is dependent on a logic model that shows how the IRCs were expected to achieve their original objectives through EPSRC funding and how the outputs of the research could lead to outcomes and, in the longer-term, impact in various dimensions. Testing these assumptions and hypotheses involves collecting and analysing quantitative and qualitative data from various sources and triangulating these to ensure minimising data gaps and reaching robust conclusions.

Therefore, we first reviewed the IRC programme's logic model, initiated desk-based research to review documentation and monitoring data available about the IRC programme, conducted a portfolio review using Researchfish and Dimensions datasets, and collected extensive primary data through stakeholder consultation (online surveys and interviews). This field research has allowed us to synthesise evidence and identify impact of the IRC programme, develop impact case studies to demonstrate tangible outcomes and make economic estimates about the outcomes and early impacts of the IRC investment.

2.1 Healthcare Technologies IRC Programme Logic model

EPSRC supplied a draft logic model for the Healthcare Technologies IRC programme as part of the specifications for the evaluation. We have reviewed and structured it according to standard evaluation practice. We prepared a graphical representation of the logic model in Figure 1.

According to the logic model, the EPSRC made a strategic intervention through the calls for proposals, provided staff to manage the competition and programme implementation, and provided the £59.1 million funding over the 10 years. The research community also contributed with ideas and existing resources to plan for and implement the research programme.

The logic model follows four impact pathways horizontally from activities undertaken within the programme generating direct outputs that can be attributed to the programme, to outcomes and impacts that emerge as a result of the IRC programme, but also external factors, such as other research projects through further funding or private investment to complementary technologies. The four impact pathways are not separate or independent but interact vertically at each stage as the causal chain of the logic model progresses from left to right.

The knowledge creation impact pathway represents the interdisciplinary collaboration across (mainly) the academic organisations to establish research excellence, produce new publications, research tools, methods and datasets that with time accrue citations (and enhanced reputation) in the international research community. The basic and applied research will generate intellectual property (that may or may not be protected) and progresses the development of new technologies (TRL 1-3), which may attract further funding to develop these technologies even further. Ultimately, the expected impact is that the new knowledge establishes the UK as an internationally leading research base in healthcare technologies, where real-world challenges are tackled with innovative new science. Importantly, the programme would create and sustain the interdisciplinary research collaboration as a new ecosystem for healthcare technologies.

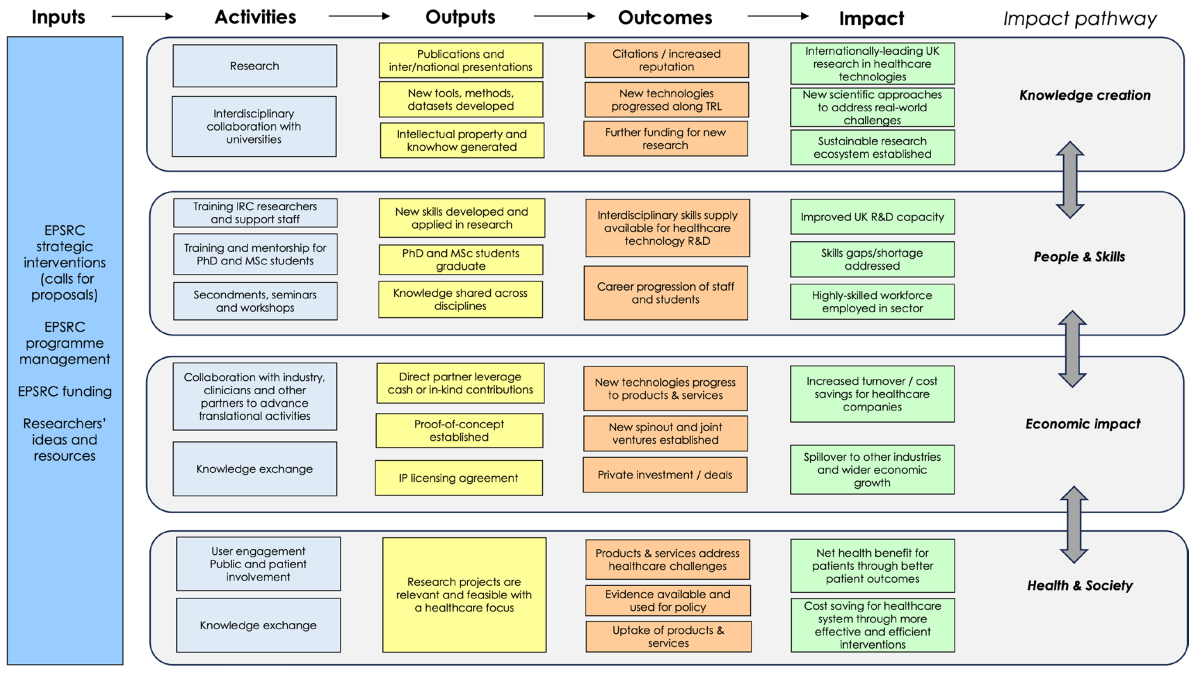
The second important pillar of the programme is 'people & skills' where IRC researchers and all staff (including management, technicians) would get trained in the relevant interdisciplinary skills, and, while studentships are not directly funded, the IRC programme would contribute to research students training and mentoring. All IRC teams would participate in seminars and workshops and the more junior staff and students would also undertake secondments in other organisations to further their research skills in other areas and contexts. This produces the new skills, sharing of new knowledge across disciplines and fresh skilled graduates for their next destination. The outcome emerging from this pathway is beyond the career progression of staff and students, the creation of a new interdisciplinary skills supply in health technologies, which, longer term, will address the skills gaps and shortages, improve the UK's R&D capacity and provide highly skilled workforce that can be employed in the sector.

The expectation of economic impact is an important one for the nation's wealth and continued capacity of innovation in a sustainable way. In this pathway, the academic research community actively collaborates (and exchanges knowledge) with industry and also with other partners to accelerate translational research. As an output, it is expected that businesses support the IRC research programme through contribution of cash, infrastructure, knowhow or other in-kind support. It will contribute to establishing a proof of concept of the original research idea and potentially agree on licencing the intellectual property generated within the IRC programme. The outcome may be the creation of new spin-outs and joint ventures that could progress the technology toward marketable products and services, which may attract further private investment into these new entities. Ultimately, these spin-outs will grow (turnover/FTE headcount) and generate wider economic impact in adjacent sectors.

Another important objective of public funding is to contribute (directly or indirectly) to the nation's health. Increasingly, it is recognised that research needs to be informed by end-users, let it be healthcare professionals who will apply these technologies or the public and patients who will benefit from their use. This will ensure that the research will be relevant to patient and user needs, that it will be conducted in a responsible way, and that the ultimate outcome will be feasible to implement in the healthcare system (such as products and services to be deployed). The evidence generated in the research will also be available to and used by decision makers to produce new guidelines, policies and practices. The expected impact is that long-term, there will be increased patient benefits through better outcomes and contribution to more effective and efficient healthcare services.

It is useful to note that the timescale to outputs is expected to be generated by the end of the research programme, but outcomes and impact emerge variably, dependent on the type of technology or research area. Some technologies may produce impacts rather fast (for example, predictive computer models within 1-2 years) while others that require the design and fabrication of a device and may need regulatory approval before being taken up in a healthcare setting, will require 5+ years. Therefore, when exploring the different IRCs, we will consider the differences in the research area but also the time available for generating output (for example, TeDDy started in 2018, five years later than the other three IRCs). Ultimately, the logic model provides an overarching framework for the IRC programme to analyse data collected and assess the extent of outcomes and early impacts against expectations.

Figure 1 Logic Model of Healthcare Technologies IRC programme



2.2 Methods and data sources

The data collection and analysis methods employed in this evaluation aim to respond to evidence needs for testing the expectations around outputs, and emerging outcomes and impact of the IRC programme. Below we provide an overview of methodologies applied and data sources.

2.2.1 *Portfolio analysis*

We analysed all portfolio level data made available by EPSRC, in particular the latest Researchfish[22] submission and Dimensions[23] data. We conducted quantitative and qualitative analysis of these two datasets, to understand the outputs, outcomes and early impacts of the programme. Preliminary analysis of the portfolio also supported the development of our data collection tools. We outline below a brief summary of the data sources, for more information and detailed analysis, see Appendix A and B.

Researchfish

Researchfish submissions by IRC researchers aim to contribute to a comprehensive and current dataset in terms of outcomes of projects funded through the IRC programme. It includes publications, spin-outs, engagement activities and other types of outputs and outcomes. We have analysed Researchfish data from the latest annual update in March 2023. Quantitative data was de-duplicated as far as possible and aggregated to obtain an overall view of the

[22] Researchfish is a technology platform to collect information from researchers and external data sources: https://researchfish.com/

[23] Dimensions is a linked research data source by Digital Science: https://www.dimensions.ai/

IRC programme (rather than analysing separate grants), and a narrative summary was provided for qualitative data.

Dimensions

Dimensions data was made available by EPSRC to complement the Researchfish analysis. This dataset includes publications, clinical trials, patents and policy documents matched to grant reference numbers or linked indirectly to the IRC programme through citations to IRC publications. The data provides an independent way to explore the IRC portfolio, cross-reference and expand data from Researchfish through an analysis of tagged research outputs (for example, authors organisation types, country affiliations, publication citation metrics, and research area classification).

2.2.2 Online survey

We conducted an online survey with all participants from the four IRCs, including academic principal investigators (PIs) and co-investigators, industry partners, NHS hospital trusts and third-sector participants. Contact information for disseminating the survey was obtained from project documentation and IRCs management teams. The survey served to update and extend data used for the portfolio analysis and provide insight into the views of research participants. It also supported the collection of data for the economic analysis and the development of case studies.

The survey was open for six weeks between mid-August and end of September 2023. A total of 145 individuals were invited, of which 45 provided answers (31% response rate). Most responses originated from researchers at universities and research institutes (n = 42). A small number of industry (n = 2) and healthcare (n = 1) partners also provided answers to the survey. Please see Appendix C for full analysis of survey results.

2.2.3 Interviews

We conducted a programme of in-depth, semi-structured, online interviews, to further our understanding of the nature and scale of the specific outcomes and impacts of the programme, and the extent to which these outcomes can be attributed to the IRC programme. Interviewees were also asked about key enabling factors, barriers encountered, qualitative counterfactual scenario and lessons learned. Interviews were essential to collect data required for developing case studies. For this reason, the selection process for inviting interviewees was driven by the list of case studies and interviewees' availability. A total of 34 interviews were conducted between September and November 2023. Most interviews were with academic researchers including seven early career researchers (n = 26), including the four academic PIs and co-investigators, but also companies (n = 5), healthcare professionals (n= 2) and external experts (n = 6). The complete analysis of interviews is presented in Appendix D.

2.2.4 Economic analysis

To evidence the IRC programme's economic impact, relevant data was collected from secondary and primary sources described above on spin-out companies created, the number of FTEs employed by these spin-outs, and the funding raised. In addition, we used data from Crunchbase and FAME and conducted additional targeted online searches. The economic contribution of the IRC funding was estimated by calculating employment creation and Gross Value Added (GVA) in 2022 and projected in 2025. Economic benefit to industry partners was not explored as no attributable equity investment or employment benefits were observed.

Our overall assessment of economic impact captures success at different stages of a company's development and combines short-term metrics that indicate a spin-out will be successful (for example, patents, collaborations, equity investment) with longer term metrics (for example, new product, employment, commercial revenue), alongside qualitative insights from case studies, to gauge the success and potential of spin-outs supported by EPSRC's funding program.

Estimating the GVA from spin-outs faces the challenge of considering the inherent time lag for these ventures to commercialise products and contribute to economic growth. Spin-outs undergo a prolonged development phase from research to market, and their employment growth may materialise over the long run. Attributing the economic impact associated with IRC funding is also challenging as researchers receive funding from multiple sources for multiple synergistic research projects that may contribute to developing the technology over many years. It is therefore often not possible to isolate and quantify the exclusive contribution of a particular funding program. Nevertheless, given the fundamental role that EPSRC funding played in the development of the relevant technologies and thus the early establishment of these spin-outs, we have assumed high additionality of the IRC funding. Without such public support, it is unlikely that the ensuing economic activity associated with these spin-outs would have happened to the same scale, within the same timeline, or with the same scope of applications.

2.2.5 Case studies

We have developed 12 case studies illustrating significant (actual and expected) outcomes and impacts emerging from the IRC programme. Case studies focused on a single well-defined project or research strand within the IRC programme to showcase knowledge generation, new science, unique partnership or particular economic/social benefit. The case studies help to understand the mechanisms, enabling factors and challenges that researchers had to tackle within their projects and in the context of the wider environment. The case studies are presented in a separate Appendix.

To provide a balanced view across the impacts IRC programme projects achieved, we used a set of hierarchical selection criteria from a longlist of case studies:

1. Balance across the four IRCs
2. Balance across the type of primary outcomes/impacts (impact pathway)
3. Funding instrument used (core IRC vs Next Step Plus projects).
4. Type of actors involved (academic researchers, industrial partners, clinicians).
5. Availability of evidence and access to key informants.

Case studies were developed using a common structure covering needs, aims of the project, description of relevant activities, contribution of IRC investment and pathways to outputs, outcomes and impacts, with quantification where possible. Each case study drew on a variety of data sources, including desk research, survey responses, interviews, and economic analysis completed as part of the evaluation. Additional interviews were conducted to fill gaps and gather perspectives of project partners.

2.3 Limitations

There have been a number of limitations that affect the robustness of the findings. First, the IRC programme is diverse in scope of its underlying projects, disciplines, and technology areas, as well as in the timelines involved in each collaboration (three collaborations started in 2013 and one in 2018). The early-stage nature of research and innovation activities funded by the IRC programme (TRL 1 to 3) also means that some outcomes and impacts may not be observed at the time of the evaluation, when many IRCs and projects are either recently completed or are still ongoing.

Second, the EPSRC's IRC programme is implemented by researchers building on existing research outputs and outcomes and with an active portfolio of often synergistic research projects funded by others. Equally, for the IRC's outputs to continue to progress towards outcomes and impacts, further funding for the IRC researchers and others are needed. For this reason, it is not always possible to fully isolate the effects of IRC funding from other sources of fundings on the IRC outputs and outcomes. This limitation is particularly relevant for the portfolio analysis which relies on research outputs (partially) attributed to IRC investment.

Third, the portfolio analysis included limitations related to the data sources, namely Researchfish and Dimensions. For Researchfish, self-reported data has an inherent but unknown level of under-reporting and over-reporting of project outputs and outcomes by researchers. For example, attribution of the same outputs and outcomes to multiple research grants were identified in Researchfish, and efforts were made to process the data to reduce their impact in the overall analysis. In the Dimensions dataset, linking clinical trials, patents and policy documents to the IRC projects through citation of publications by IRCs may overestimate the direct impact of the programme. Further, coverage of certain tags or attributes of projects and their outputs were not complete, and aggregation of these characteristics potentially introduce biases.

Fourth, data triangulation was challenging as some information reported from different sources resulted in partial and conflicting information. A case in point is our reporting on patents, where the Researchfish and Dimensions datasets contained considerably different information, and information from interviewees and contact with individual university technology transfer offices were needed to consolidate information, using a hierarchy of evidence approach.

Fifth, due to the 5-10-year period in scope for the evaluation, staff turnover in organisations over time limited access to staff who contributed to the programme and potentially hindered the identification of additional benefits. Project monitoring and management data was not always available or consistent across the IRC programme to fill this gap.

Sixth, stakeholder engagement for data collection activities proved challenging. While several actions were taken to engage individuals, including through personalised reminders and dedicated support by IRC management teams, many individuals were unavailable or too busy to respond to our consultations. For this reason, the response rate for the online survey was relatively low, particularly impacting information obtained from non-academic partners, such as companies and healthcare organisations. It is likely these organisations were involved in an advisory capacity and/or provided limited input to research implementation at various stages of the programme.

The programme of interviews was not fully able to cover data gaps and thus the lack of engagement from companies partially affected the economic analysis, as potential benefits of IRC involvement to partnering companies were less explored. Nevertheless, case studies provided rich data on actual and expected outcomes of individual and specific projects contributing to the overall impact of the IRC programme.

3 Results and Discussion

In this section, we present the synthesis of our findings and follow the logic model of the Healthcare Technologies IRC programme: how the various activities implemented by the four IRCs led to results and emerging impact on knowledge, people and skills, economy, and health & society.

3.1 Impact on knowledge

IRC research projects generated a wealth of new knowledge that is manifested in many different forms: from academic peer-reviewed publications and conference presentations to new research tools, methods and models to specialised knowhow and protected intellectual property. These are created through interdisciplinary collaborations across universities, industry, healthcare organisations and beyond. It contributes to enhanced skills and capabilities of researchers participating in these collaborations and forms the basis of building UK capacity and leadership in healthcare technologies. Note that new knowledge published as patents is discussed in the economic analysis section.

Publications

Portfolio analysis from Researchfish data showed that the IRC programme generated overall 683 publications, 30 new databases and datasets, 15 research tools and methods, 11 distinct software and technical products, and 11 intellectual properties, among others. IRCs, each with their different research focus and approach, disseminated the new knowledge in different ways: SPHERE published over 300 research articles and reports, i-sense generated over 25 different datasets and research tools/methods, and Proteus produced 7 intellectual properties. It is important to note that these quantitative figures provide an indication of intensity of knowledge generation activities, however, only qualitative research can openly reveal the quality of these research outputs and outcomes. More information on Researchfish analysis is available in Appendix A.

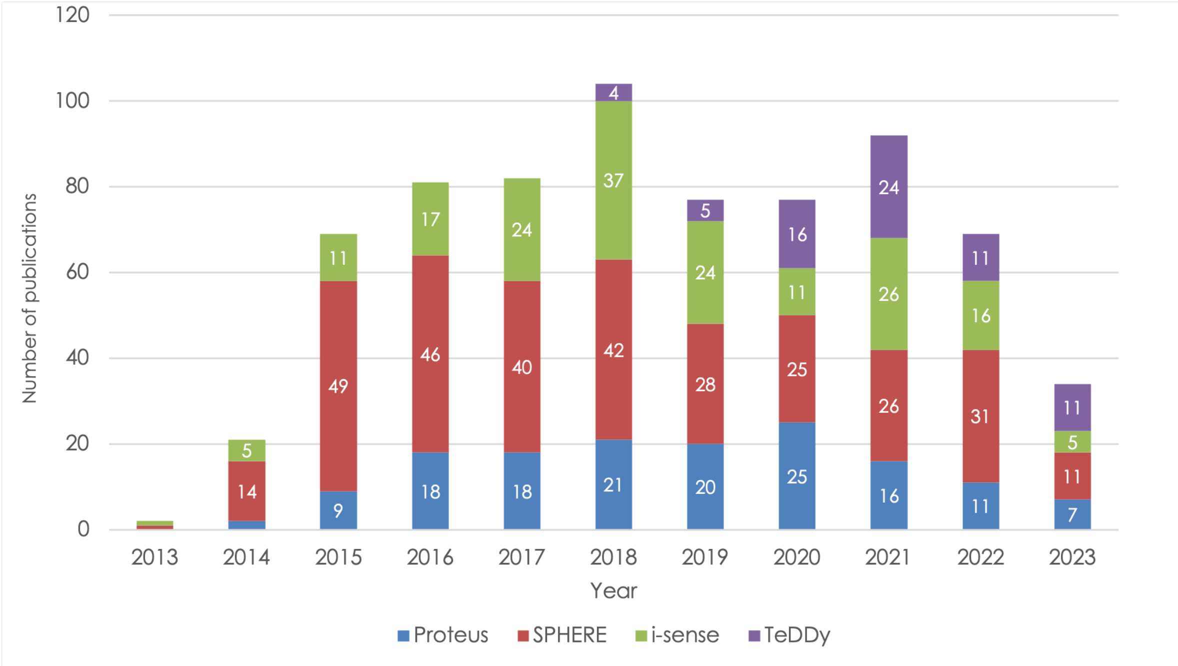
An analysis of the Dimensions dataset provides a more nuanced view of the knowledge generated in healthcare technologies through publications attributed to IRC funding. First, we provide an overview of the number of publications per publication year in Figure 2. It shows that after a lag of up to two years, the total number of publications per year appear to grow, reaching a peak in 2018. It is likely that the focus of the three original IRCs changed in the second funding phase of the programme, from generating and disseminating research results, to applying the research in various settings. Some finer effects are also observable, for example, i-sense's work on COVID-19 response[24] show an increase in publications in 2021 or that SPHERE publishes more and earlier than other IRCs. Interestingly, while peer-reviewed articles dominate research publications for all IRCs, many additional proceedings were also identified for SPHERE (see Appendix B). It can be explained with SPHERE's focus on electrical engineering and computer science, disciplines where researchers typically present their work first in conference proceedings[25].

---

[24] https://www.i-sense.org.uk/covid-19/covid-19-response

[25] https://onlinelibrary.wiley.com/doi/abs/10.1087/20130307

Figure 2 Number of publications per publication year



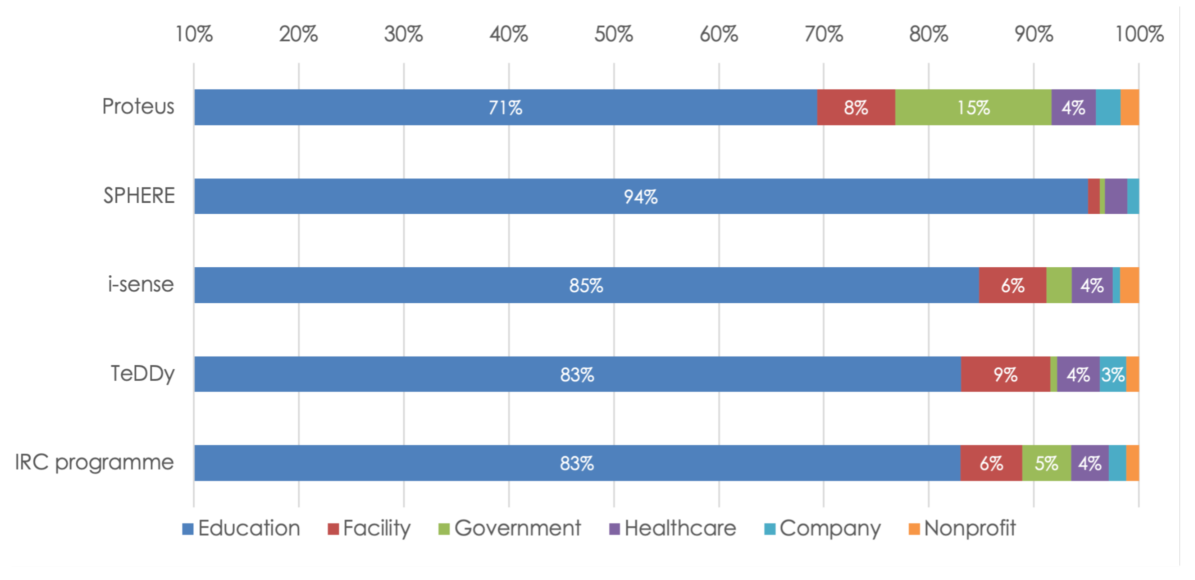
Source: Technopolis analysis based on Dimensions data. Note: no complete data is available in the dataset for year 2023.

We also analysed authors' affiliated organisations by their types for each IRC publication, as a proxy for academic co-investigators and non-academic partners (for example, research institutes/facilities, government agencies, healthcare organisations, industry or non-profit sector) contribution to the body of research executed throughout the IRC programme (Figure 3). Over 80% of IRC authors' organisations are of 'Education' type (universities), with 11% attributed to 'Facility' (6%) and 'Government' (5%). The difference in co-authors' organisation types for IRC Proteus publications is visible: relatively lower share of academic co-authors and more from government agencies.

Overall, healthcare organisations, companies and non-profit organisations represent a relatively low level of co-authorship of publications by the IRC programme. It is possible that the focus on basic research and low technology readiness level (TRL) technology development may have constrained collaborative opportunities outside universities and research institutes. In addition, it is likely that healthcare organisations, industry and non-profit organisations provided advisory inputs during their collaborations rather than actively contributing to implementation of research.

We also looked at the average number of different organisation types involved in publication as an indication of the extent to which the IRC programme has resulted in collaborations with different organisation types over the years. A small positive trend was observed since the start of the IRC programme for all individual IRCs (see Appendix B). While at the start of the programme the average number was close to 1 (i.e., academic only publications), it rises to 1.5, indicating other organisation types regularly co-author papers with academic researchers. This may be due to the effective utilisation of the IRC programme's partnership resource fund, which allocates 10% of the overall IRC funding to exploring new collaborations. In the case of i-sense, the increasing trend is clearly observable over the years. Nevertheless, when looking specifically at the academic-industry co-publication in the IRC programme, only 26 publications out of 656 (where organisation types were provided in the dataset) were identified as such, indicating a modest industry involvement in research implementation.

Figure 3   Share of authors' organisations by organisation type, over all years



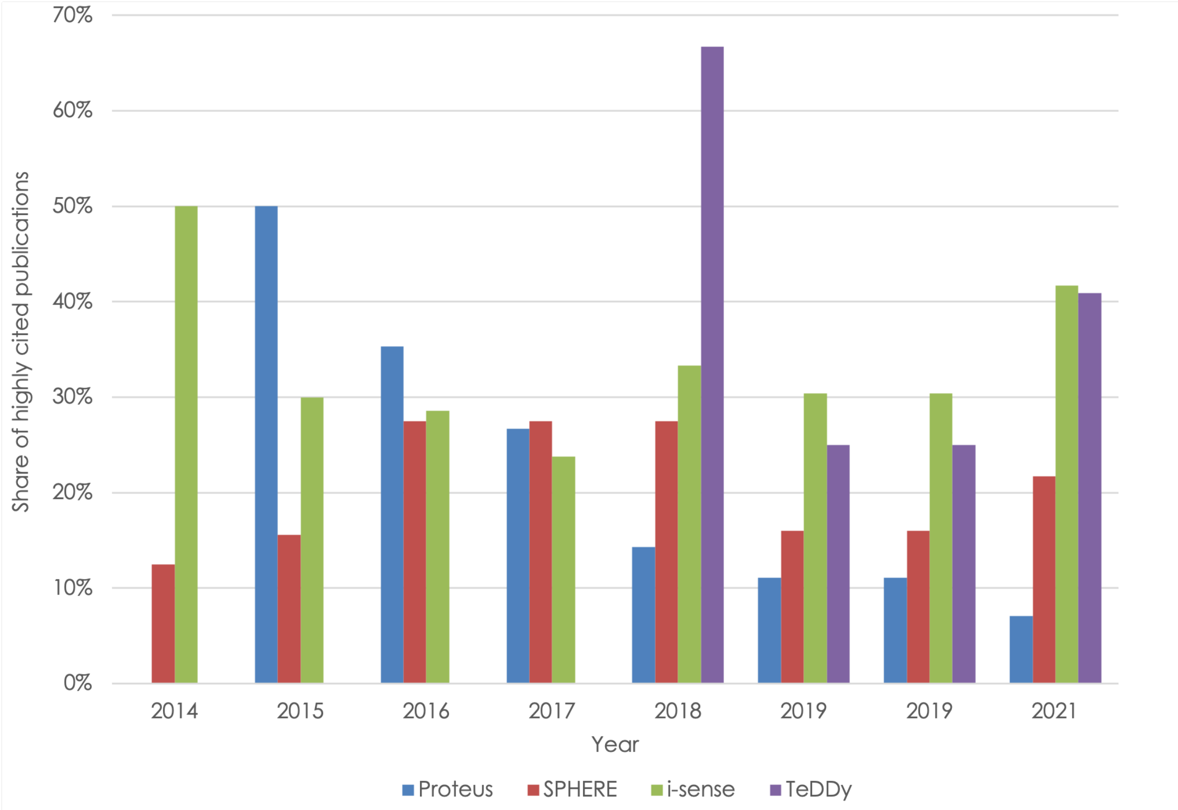
Source: Technopolis analysis based on Dimensions data. Note that not all IRC publications were tagged with organisation type in the dataset.

We also analysed the share of publications with co-authorship from two (or more) different countries per publication in each year as a proxy for the existence of international collaboration. An upward trend is observed between 2014 and 2020, with share of multi-country publications doubling to reach nearly 50% of all publications for each IRC (see Appendix B). Across all years, approximately 30% of all IRC publications were the result of collaborative efforts between authors from at least two different countries. Looking at individual IRCs, i-sense had the highest share of international collaborations as measured by its publications' co-authorship countries.

We also studied the citation characteristics of IRC publications as a measure of diffusion of the new knowledge generated by the IRCs in the scientific community or indication of its scientific impact. IRC publications had, on average, accumulated around 30 citations per publication since their respective publication year to September 2023 (see Appendix B). Looking at individual IRCs, i-sense had the highest average total citations of about 70 per publication between publication years 2014 and 2021. The highest cited i-sense papers were published in Science and Nature journals and obtained over 500 citations each.

It may perhaps be more revealing to look at the IRC programme's contribution to 'highly cited' publications where field citation ratios (FCR) are calculated (where the citation of a publication is compared to all others published in the same year and within the same field of research). A publication is 'highly cited' if it is in the top 10% of all field citation ratios and may serve as a proxy of research excellence. Figure 4 shows the share of highly cited publications per publication year among the IRC programme's research outputs.

Figure 4 Share of highly cited publications per publication year



Source: Technopolis analysis based on Dimensions data. No highly cited publications identified for year 2013. Years 2022 and 2023 were removed as FCR is calculated for publications of 2 years or older.

Over a quarter of all IRC publications are 'highly cited' publications (n = 145, 27%). Nearly 70% of these highly cited publications (n = 99) have a FCR value of 10 or higher, which means these publications have more than 10 times the citations of the average publication in the same field of research in the same year.

Finally, we analysed the research categories that were associated with each of the publications to identify the focus areas of IRC research. Note that one publication may have more than one associated research category. These categories are defined in various different standard classification schemes.[26]

The share of fields of research categories varies within and across IRCs, according to their specific research focus, demonstrating a high level of interdisciplinarity of individual IRCs and the overall IRC programme (see Appendix B). For example, SPHERE's publications are focused on the field of Information and Computing Sciences (>60%); publications by i-sense and Proteus exhibit highest disciplinary diversity with the top 60% shared across three different fields of research, and Teddy across two different fields of research. All four IRCs have contributed to

[26] We analysed tags from the UK's Health Research Classification System (health category, HRCS-HC and research activity code, HRCS-RAC), ANZSRC Field of Research (FoR) categories (Australia and New Zealand), and the US NIH Research Condition and Disease Categorization (RCDC) system. Note that not all publications were tagged in the Dimensions dataset, and the most complete coverage (ca. 90%) was achieved for the FoR categories.

the following key fields of research to varying degrees: Engineering, Physical Sciences, Biomedical and Clinical Sciences, and Information and Computing Science.

A more granular field of research categorisation was also analysed, providing a unique signature for each IRC's research activity. For example, Proteus contributed to Electronics, Sensors and Digital Hardware; Data Management and Data Science, but also to Atomic, Molecular and Optical Physics; Clinical Sciences; and Ophthalmology and Optometry. SPHERE on the other hand contributed to Data Management and Data Science; Human-Centred Computing; Machine Learning; and Communications Engineering, among others. i-sense's research contribution was spread across Clinical Sciences; Medical Microbiology; Health Services and Systems; Public Health; Biochemistry and Cell Biology; and Macromolecular and Materials Chemistry. TeDDy's fields of research included Biomedical Engineering; Pharmacology and Pharmaceutical Sciences; Medical Biotechnology; Materials Engineering; and Oncology and Carcinogenesis.

Other research category classification schemes confirm the previous finding that IRC publications show great diversity of research areas and aligned with the stated focus of individual IRCs. The RCDC scheme shows that publications from each IRC were associated with Bioengineering to a considerable extent, with a large share of publications produced by i-sense and Proteus associated with 'Infections' and TeDDy with 'Cancer' health category (HRCS-HC), while SPHERE's main focus was categorised as 'Generic health relevance'. In terms of the research activities (HRSC-RAC) of the three original IRCs, 'Discovery and preclinical testing of markers and technologies' was prominent. SPHERE's other focus was on 'Individual care needs' and TeDDy's on 'Pharmaceuticals'.

Overall, IRC funding to UK researchers enabled internationally leading, highly cited publications, among other types of research outputs (for example, tools, datasets and dissemination of those in conference presentations), thus increasing the UK's reputation in healthcare technologies research.

New networks and partnerships

A key objective of the IRCs is to create new opportunities for collaborations across disciplines, through the establishment of new research networks and partnerships. The core of these collaborations are universities, however, also complementing and strengthening their expertise by including industry partners, clinicians, policy makers and end-users, to ensure relevant research is progressed faster towards new products and services.

The authorship composition of research publications showed that over 80% of IRC authors' organisations are universities, the remainder were from research institutes and government organisations, with few from healthcare organisations, companies and non-profit organisations. What this figure does not reveal is the extent to which these authors had (or not) collaborated before. Over half of the survey respondents (57%) stated that they had no previous collaborations with their IRC partners and a further one quarter (23%) noted partial involvement with one or more IRC partners (detailed survey results are available in Appendix C). This clearly shows that the IRC programme was successful in bringing new partners together for long-term collaboration addressing challenges in healthcare technologies. Over 70% of survey respondents noted that the partnerships involved exploration of new research areas, basic applied research and proof of concept studies, and collaborations with researchers from different disciplines and with end-users (including patients and healthcare professionals). While these collaborations have not yet resulted in joint research publications, survey respondents stated that engagement with clinicians was a key factor to advance their research towards translation and deliver impactful research outputs. In their view, the scale and timeframe of funding were the key enablers of the IRC programme to tackle big challenges in healthcare technologies.

Rating of 'collaboration with businesses' was divergent and qualitative answers confirmed this lack of consensus. Those that had industry engagement expressed positive views (from three IRCs), while others noted limited industry input due to the early stage of their research (from two IRCs). Collaboration with international researchers, UK government organisations and third sector organisations was also rated relatively lower. Yet, i-sense, in particular, established linkages with the World Health Organisation (WHO) and Public Health England/UK Health Security Agency through their work on novel digital epidemiological approaches to monitoring influenza and COVID-19 outbreaks (see more on this topic in Box 10).

On the sustainability of the established collaborations, two thirds (65%) of survey respondents indicated they have continued (or will continue) collaborating with IRC partners beyond the IRC programme, and a further one quarter (25%) indicated partnerships are likely to continue. This shows clear progress toward creating a sustainable research ecosystem in healthcare technologies in the UK.

A case in point is i-sense's research and development of ultrasensitive diagnostics tools for infectious diseases that opened up a new opportunity to partner with the Africa Health Research Institute (AHRI) to progress HIV surveillance in rural South Africa by improving the interpretation of commercial diagnostic tests (see more information in Box 1).

Box 1 m-Africa: mobile phone-connected diagnostic for HIV prevention and management

Closing the gap between HIV testing and treatment is essential to reduce HIV incidence, transmission and mortality, and to ease the burden on primary healthcare. Mobile health (mHealth) approaches have the potential to widen access to HIV testing and improve access to care. Combining HIV disease diagnostics with mobile-phone technologies that link to care providers would enable individuals to self-test at home, report the results to healthcare professionals and access care if needed.

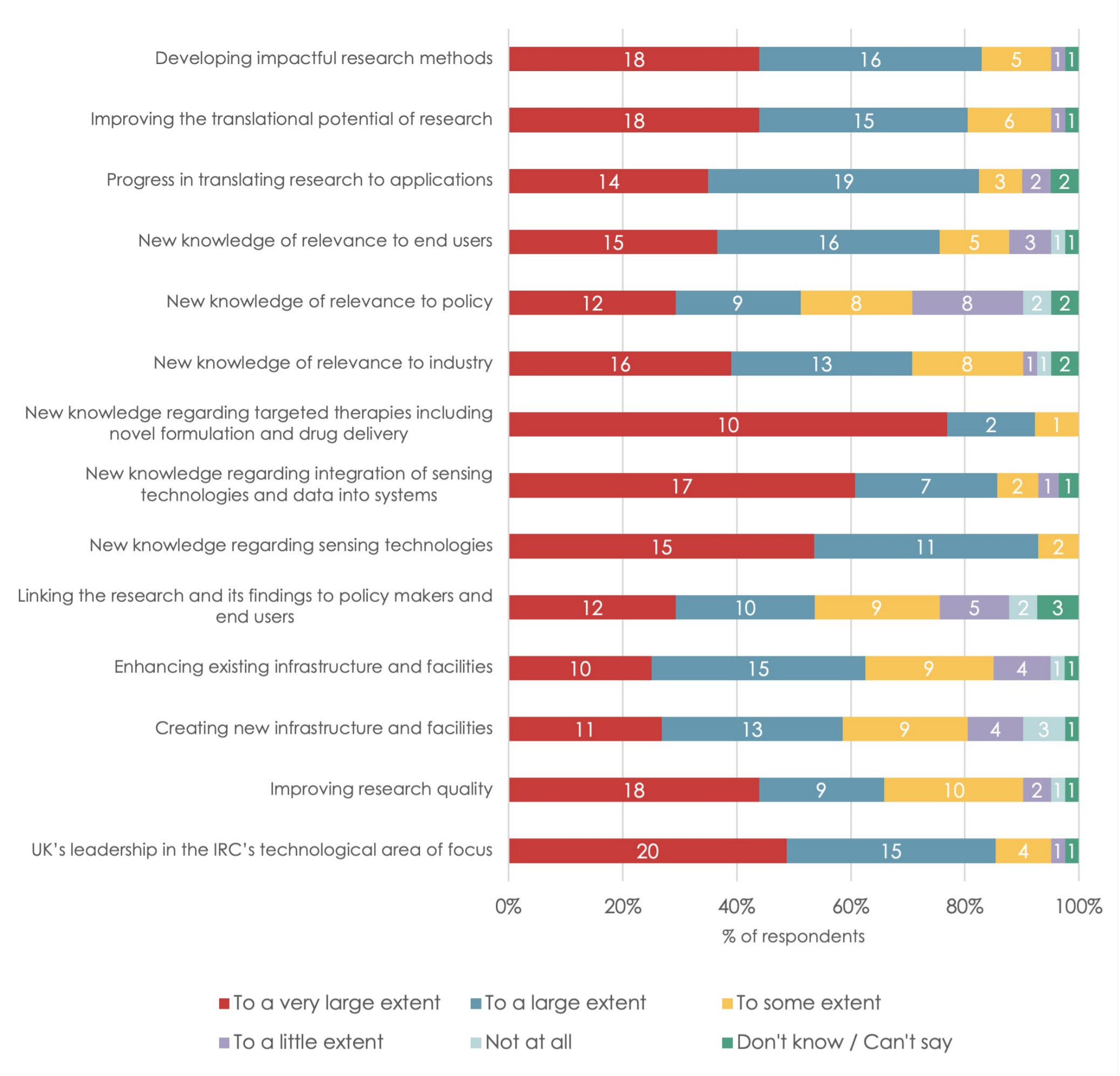
IRC i-sense researchers in collaboration with the Africa Health Research Institute (AHRI) in South Africa developed a mHealth app that uses a machine learning model to interpret the results of commercially available lateral flow tests for HIV. The app can improve the accuracy of HIV lateral flow test interpretation compared to visual inspection and thus contribute to reducing the number of false positive/negative test results. This in turn has the potential to support field worker training, strengthening healthcare system efficiency and improving patient outcomes. This project produced key outputs for the use of mHealth and machine learning for diagnostic analysis beyond testing for HIV:

- The machine learning model developed was used by researchers at Imperial College London to analyse over 500,000 COVID-19 lateral flow tests. The findings support the use of machine learning-enabled automated reading of at-home lateral flow tests to improve the accuracy of population-level community surveillance.
- While the mHealth app developed could not be implemented across South Africa due to limitations in the healthcare system, AHRI researchers are planning to apply the machine learning image data collection approach to patient immunisation cards and paper-based medical records to automatically create electronic patient records.

Research and scientific impact

Measuring the IRC programme's contribution to research and scientific impact is complex and evidence of impact requires time to emerge. Nevertheless, according to IRC researchers, the programme has already contributed to many relevant aspects of impact pathway linked to creation of new knowledge (see Figure 5).

Figure 5 Outcomes of the IRC programme's contribution to research and science



Source: Online survey results with IRC programme researchers

Over 80% of survey respondents considered the IRC programme had made significant contributions (to a large or very large extent) to new knowledge in the IRC's focus area of research (sensing technologies and targeted therapies). The emergence of highly cited publications by the research community also attests to this achievement (Figure 4). Three quarters of survey respondents stated that the IRC programme contributed to new knowledge relevant to end-users to a large or very large extent, and to a smaller extent relevant to industry.

In addition, respondents also rated highly other aspects enabled by the IRC programme, such as 'developing impactful methods', 'improving the translational potential of research', and 'progress in translating research to applications'. This indicates an overall positive view about the IRC programme as an enabler of impactful research outputs and explains that 85% of respondents consider that the programme contributed to a (very) large extent to the UK's leadership in healthcare technologies.

For other aspects, there was relatively less consensus among respondents, such as the IRC's contribution to creating or enhancing existing infrastructure, improving research quality, and informing policy and linking findings with end-users; nevertheless, over half of the respondents rated the programme's contribution to these aspects highly. External stakeholders noted in interviews that they would have wanted to see more industrial and clinical input into the IRCs work in order to accelerate further the translational activities.

There are many examples where research knowledge generated in the IRCs has contributed to new scientific approaches to address real-world challenges and progress translational research. IRC SPHERE highlighted the programme enabled critical research on the ethical aspects of collecting data from home monitoring technologies. SPHERE created scripted datasets with robust annotation and curation, enabling further research into multi-sensor technologies. The SPHERE House dataset has been used in machine learning competitions, teaching, development and validation of activity recognition algorithms (see Researchfish analysis in Appendix A). SPHERE's 'Next Step' project, OPERA, generated a wealth of new knowledge by integrating passive sensing approaches with other systems developed in SPHERE (see Box 2).

Box 2 Opportunistic Passive Radar for Non-Cooperative Contextual Sensing (OPERA)

Contextual sensing can be used to monitor human activity and health metrics in the home, in order to detect health issues and trigger timely interventions. These types of Ambient Assisted Living (AAL) technologies hold the promise of enabling people to live healthy, independent lives for longer, and thus reduce the burden on healthcare systems.

The OPERA Project (Opportunistic Passive Radar for Non-Cooperative Contextual Sensing) was funded by an IRC 'Next Step Plus' award from January 2019 to March 2023. It aimed to develop contextual sensing technologies capable of passive sensing to recognise physical activity and localisation in the home. Researchers developed and integrated two passive sensing approaches with other sensing systems of the IRC SPHERE, achieving validation of their system. Their findings have produced several outputs, including 19 conference proceedings, 14 journal articles and three annotated datasets and a simulation tool (open access).

Having validated the technology in a laboratory environment (Technology Readiness Level 4), the OPERA team are now looking to secure funding to test the technology in a real-world healthcare setting (TRL5), in collaboration with the NHS. The technology developed also has the potential to be applied in fields beyond healthcare and is already being tested for use in surveillance and law enforcement.

For Proteus, the IRC enabled pursuing new research areas, such as healthcare photonics, with promise for using the imaging platforms in intensive care units; these scientific results are being further tested in clinical trials and commercialised for future exploitation (see more on patents and spin-outs by Proteus in the section on Economic impact below). IRC TeDDy noted that the highest potential for future impact from their research will be a device for continuous delivery of drugs using electrophoresis and injectable hydrogel for better delivery of drugs for brain tumours (see Box 3). Through a new spin-out, TeDDy also aims to test new materials in the future, such as metal organic frameworks, to improve effectiveness of therapies for hard-to-treat cancers.

Box 3 Dynamic hydrogels as a platform for local drug delivery

Current standard treatment for cancer involves surgical removal of the cancer followed by chemotherapy and/or radiotherapy to destroy any remaining cancerous cells. However, in the case of hard-to-treat cancers, complete removal of cancerous cells is difficult.

In 2018, IRC TeDDy set out to develop injectable hydrogels for drug delivery systems to improve encapsulation and release of a wide range of therapeutic drugs. Building on previous research, researchers developed a robust manufacturing scale up and sterilisation protocol for the hydrogel drug delivery system in line with good manufacturing practice (GMP) requirements. This is a key step to progressing the technology and further testing in clinical trials.

As a result of this project, researchers were able to test a variety of scale up and sterilisation protocols to produce the hydrogel formulation in sufficient quantity necessary for clinical studies. Results of this work are expected to be published in the near future and further funding will enable the manufacture of hydrogel to GMP standards.

i-sense has created several databases, mobile applications and a novel biomarker discovery software platform (IDRIS) to facilitate the analysis of genome sequence data from bacteria, to aid development of diagnostic sensors; i-sense pioneered ultrasensitive diagnostics tools for infectious diseases (Box 4) and developed new digital epidemiology to support surveillance systems (see Box 10 in Health and Society section).

Box 4 Ultra-Sensitive Enhanced NanoSensing of Anti-Microbial Resistance (u-Sense)

Rapid and early identification of antimicrobial resistant (AMR) infections in patients allows for quick medical treatment, which reduces the fatality rate and healthcare costs. To select the appropriate treatment, it is important to identify not only which bacterial species is present in a patient sample, but also to which antibiotics the bacteria are resistant. However, few accurate technologies capable of rapidly identifying AMR strains are currently available.

In 2018, the u-Sense project, funded through a Next Step Plus award to IRC i-sense, set out to develop diagnostic tests capable of detecting bacteria as well as antibiotic resistance. Researchers used an ultra-sensitive detection method, Surface-Enhanced Raman Scattering (SERS), to simultaneously detect two protein biomarkers for Clostridium difficile, the main cause of infectious diarrhoea in hospitalised patients. This test is now ready for clinical evaluation.

In addition to the above, the project collaborators combined several novel approaches to target identification, amplification and signal detection, and they are developing a test capable of detecting five resistance genes to the last-line antibiotic carbapenem. Results from this work are expected to be published in the near future. In addition, u-Sense collaborators at Imperial College London are progressing a 'simplified', affordable SERS detection system that can be used at the point of care.

3.2 Impact on people & skills

The structural setup of the IRCs across disciplines and sectors, along with knowledge sharing and training activities, geared the programme towards enhancing skills, contributing to career development and building a critical mass of researchers in the healthcare technologies. At the start of the programme, each IRC set out a list of objectives for contributing to capacity building and career development of postdoctoral researcher associates (PDRAs) and PhD students[27] associated with the IRC. Table 3 below provides a summary of these objectives.

[27] Note that no fellowship funding was available to PhD students via the IRC programme grant

Table 3 IRC objectives for capacity building and career development

IRC	Capacity building and career development objectives
i-sense	To train a new generation of researchers to become future leaders with the necessary interdisciplinary skills to tackle infectious diseases through an internal 'Education Alliance' programme, which would provide training and deliver workshops. Mobility fellowships were also created to enable engineering and physical scientist researchers to work within public health organisations and research institutes[28].
Proteus	To provide a fertile interdisciplinary environment for training a new cadre of translational scientists in the physical and biological disciplines to allow reaping the clinical and commercial dividends of a new scientific era[29].
SPHERE	To ensure PDRAs, PhD and MSc students associated with the IRC have the unique day-to-day experience of working with world-class clinical specialists[30].
TeDDy	To support career development of PDRAs within or outside academia, through mentorship programmes, seminars, secondments, and workshops[31].

The IRC programme has helped to build critical mass in the technological areas of focus through various training and skills development activities, according to over 80% of survey respondents (Figure 6). Indeed, based on data made available to the study team, at least 160[32] early-career and mid-career researchers benefited from various training and career development activities throughout the IRC programme, including PhD students, PDRAs, research associates, and other academic staff (Appendix H). The programme also enabled professional development, collaborations across sectors, and strengthened interdisciplinary skills and specific skills relevant to healthcare technology (Figure 6). Survey respondents highlighted that the participation in the programme has increased their and their colleagues' interest and skills in translational research and improved their ability to collaborate with end users. Overall, the programme has contributed to increased interest in innovation in novel health technology areas, created connections and networks, and provided a strong basis for further research funding. Three-quarters of the respondents also confirmed that within the respondent's organisation, the IRC programme led to increased interest and openness to conduct interdisciplinary research.

[28] i-sense case for support form 2013

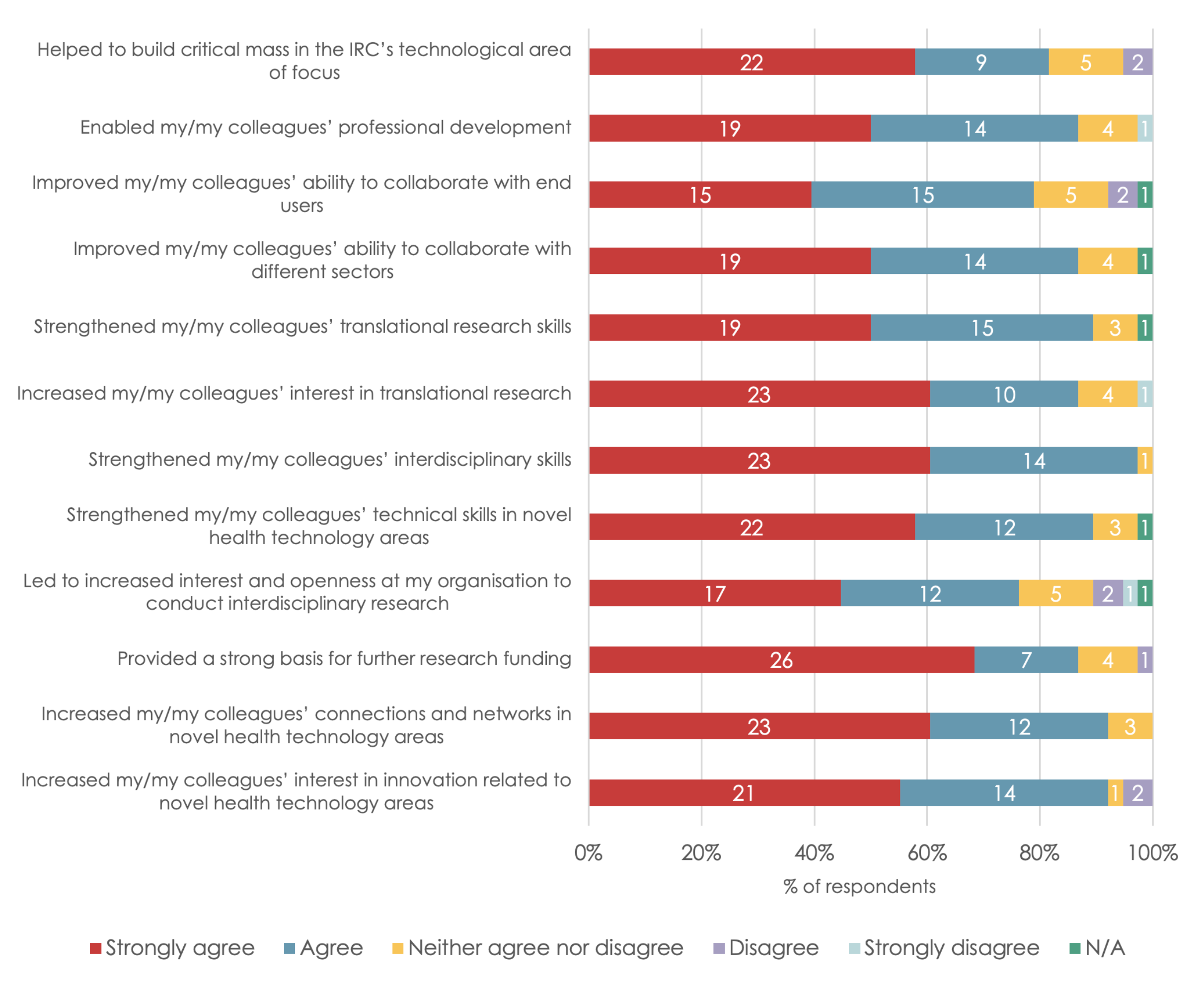
[29] Proteus case for support form 2013

[30] SPHERE core proposal form 2013

[31] TeDDy case for support form 2018

[32] Note that we were unable to receive information on the number of students from IRC SPHERE and thus the total number of early- and mid-career researchers represents an underestimate.

Figure 6 Outcomes of participation in the IRC programme regarding skills & training



Source: Online survey results with IRC programme researchers

The IRC programme has supported the development and delivery of new courses and training to develop skills around novel health technologies, translational and interdisciplinary research (see Appendix C). Courses were also developed and delivered in other, more specialised areas, such as research communication, research ethics, intellectual property protection, and to a lesser extent, good clinical practice. This is because IRCs benefited from existing courses and trainings available at participating universities, rather than creating new formal courses.

In addition to training, other activities such as participating in conferences and career development events played a vital role in connecting individuals with job opportunities, placements and secondments. Researchfish data on 'next destinations' (n = 117) and secondments (n = 32) suggests many PDRAs, PhD students and others associated with the IRC have moved to new roles. Several examples were provided in stakeholder consultations, with researchers moving to research institutes, universities, companies and other organisations:

- Several PDRAs reported new technical roles in established companies and start-ups in the fields of information technology, pharmaceuticals, life sciences instrumentation, semiconductors and others

- PDRAs also reported new academic roles including lectureships and postdoctoral research roles in the UK and abroad
- PhD students reported secondments and postdoctoral research roles at various universities and research organisations, such as the World Health Organization, the Clinton Health Access Initiative and the UK government's Joint Biosecurity Centre.

A programme of interviews with PDRAs and PhD students provided further insight how the interdisciplinary research environment, IRC meetings, workshops and training activities, and mobility fellowships contributed to learning new technical and management skills to further their professional careers.

Interdisciplinary research environment

Early-career and mid-career researchers highlighted that the interdisciplinary research environment was a key element to their progress. Participating in collaborative projects with IRC researchers and beyond, the programme exposed them to other disciplines, experts and clinicians from different backgrounds. Cross-cutting themes (for example, manufacturing practices at TeDDy) helped researchers to consider translational challenges early on and understand barriers to adoption of technologies in healthcare settings. The research projects also enabled PhD students and PDRAs to produce high-quality research papers and disseminate their work to a wide audience at international conferences.

At the start of the programme, some PhD students had limited technical skills. Through mentorship activities, lab training and secondments, the IRC programme enabled them to develop relevant technical skills, which have facilitated subsequent career progress within and outside academia. For example, as a result of participating in TeDDy, one PDRA at the University of Cambridge noted significant improvements in their coding skills, which would not have happened without the support from the IRC programme. Similarly, a former PDRA at SPHERE reported the development of technical skills in computer vision and machine learning. A former PhD student from Proteus highlighted that working with optical medical imaging systems at the IRC enabled them to develop a broad range of 'rare skills' in physics and healthcare. Importantly, some IRC projects helped PDRAs to gain an understanding of the challenges around conducting research in resource-limited settings. For example, a former PDRA from i-sense was involved in the implementation of large-scale population surveys in South Africa, in partnership with the Africa Health Research Institute (AHRI) in KwaZulu-Natal, South Africa (see more about the mAfrica project in Box 1).

IRC meetings

Regular meetings to track project progress and to promote knowledge exchange activities were highlighted by interviewees as important factors to the success of skills development. IRCs conducted meetings with the entire team to track-progress and milestones, along with weekly presentations from associated PhD students and monthly reports from project staff. As part of these meetings, PhD students had the opportunity to present their works to other IRC staff, which helped them to develop their communication and presentation skills. This has strengthened their leadership skills and empowered them to become future research leaders.

Workshops and training activities

All IRCs organised and delivered workshops and training activities to enable PhD students and PDRAs to learn new technical and non-technical skills. IRC i-sense established an internal programme named 'Education Alliance' in 2014, to introduce new dedicated teaching and training events to grow the interdisciplinary skills of PhD students and early career researchers. The programme was designed to inspire i-sense members and prepare them for future careers[33]. Education Alliance workshops covered various themes such as enterprise, innovation, commercialisation, communication and presentation skills. A key example highlighted in interviews was a data visualisation masterclass, facilitated by the Guardian. The aim of the masterclass was to provide i-sense researchers with the tools to support their presentation and dissemination activities[34].

In addition to workshops and training, interviewees from all IRCs highlighted the importance of career talks and mentoring sessions. These activities helped PDRAs to understand career options within and outside academia and connect researchers with secondment opportunities in industry. A detailed list of workshops and training activities delivered by each IRC is available in Appendix G.

Mobility fellowships

Mobility fellowships have enabled researchers at IRCs to train and work with leading national and international teams in industry, healthcare, government agencies and research institutes. i-sense's mobility fellowship scheme showcases how the IRC programme contributed to enhancing research skills in healthcare technologies (Box 5).

Box 5 i-sense Mobility Fellowships

At i-sense, mobility fellowships provided a maximum allowance of up to £10,000 per fellowship to cover travel, subsistence costs, and course fees from the Partnership Resource Fund[35]. In total, i-sense provided 16 mobility fellowships to PDRAs, PhD students and other academic staff.

Researchers made use of this opportunity to acquire new research skills through placements with leading research groups in the USA, Australia, South Africa, Myanmar and other countries. For example, a former PhD student from Imperial College London received a five-week placement at the Cluster for Advanced Macromolecular Design at the University of New South Wales in Sydney, Australia. The aim of the placement was the acquisition of polymer chemistry skills for the development of an enzyme responsive polymer-based platform for enabling early HIV detection[36].

The funding also helped researchers to gain understanding of the local challenges involved in implementing healthcare technologies. A former PhD student from University College London worked for seven weeks at Population Services International (PSI) in Myanmar, to support the introduction of HIV self-testing in the country. PSI is a global network of local organisations working to bring healthcare closer to those most in need[37]. At PSI, the PhD student designed the timeline, protocol and study for the organisation's approach for implementing HIV self-tests at scale for target populations in Myanmar. Other researchers visited and trained at the World Health Organization, Massachusetts Institute of Technology, the Africa Health Research Institute and other organisations.

In summary, the IRC programme has provided an important training ground for early and mid-career researchers to acquire relevant skills in interdisciplinary research and support their career progression. Researchers at the IRCs worked in a real-world interdisciplinary research environment, benefitting from both day-to-day training and formal training activities, in technical areas such as good manufacturing practices and diagnostics development. In addition, non-technical training in a wide range of topics helped to strengthen researchers'

[33] Education Alliance. https://www.i-sense.org.uk/research-and-training/education-alliance

[34] Education Alliance statistics and data visualisation workshops. https://www.i-sense.org.uk/education-alliance-statistics-and-data-visualisation-workshops-0

[35] i-sense internal funding opportunities. https://www.i-sense.org.uk/projects/i-sense-internal-funding-opportunities.

[36] https://www.i-sense.org.uk/science-sunny-sydney

[37] Population Services International. https://www.psi.org/about/

knowledge relevant to academia and beyond, such as in research ethics and commercialisation activities.

By establishing training opportunities, the programme has contributed to the UK's skills supply for research and innovation in healthcare technologies, in particular, sensing systems for healthcare and targeted therapeutics delivery. This new cohort of researchers will strengthen the UK's capacity to conduct interdisciplinary research and supply highly skilled professionals to industry, government, healthcare and other organisations, as evidenced above. It is likely that in addition to the 160+ early-career and mid-career researchers that directly interacted with the IRC programme, a much larger number of researchers will benefit from the programme in the future through their multiplier effect.

The IRC programme also helped to drive institutional change within participating universities. Survey respondents already noted the positive change in interest and openness of participating organisations to conduct interdisciplinary research in healthcare technologies and support the new research direction. For example, at the University of Bristol, the progress in digital health made by SPHERE has led to the establishment of a new MSc in Digital Health and a new EPSRC-funded Centre for Doctoral Training (CDT) in Digital Health and Care[38].

Together, the findings suggest that the IRC programme had played a substantial role in enhancing specialist skills and creating capacity for UK research and innovation in healthcare technologies for the future. Most case studies demonstrating impact in knowledge creation, economic impact and health & societal impact include elements of training and new skills developed within the project (see Case Studies in the Appendix).

3.3 Economic impact

There are various ways the IRC programme has leveraged additional public and private funding and used existing infrastructure to ensure efficiency and sustainability of the IRC investment into UK healthcare technologies research. The programme has also created new intellectual property and knowhow that underpin new spin-out companies that will continue developing and commercialising new products and services for healthcare. In this section, we first review the IRCs' industry partners, further funding obtained and employment generated as a result of researchers' participation in the IRC programme; next we review the patents (both pending and granted) that can be linked to IRC research directly and those additional patents that are citing new research knowledge generated by the IRC programme. We then examine the spin-out companies, employment and further investment into these, to estimate the gross value added (GVA) derived from the IRC's spin-outs, based on information to date.

Key industry partners

One of the key benefits of the IRC investment includes the establishment of new partnerships with a range of industry partners, to complement the expertise of academics and improve the potential for translational impact of research. Ten key industry partners collaborated with IRCs, including multinational and national businesses. Examining industry partners provides insight into the programme's ability to attract established corporations such as AstraZeneca, Google, Microsoft and Toshiba, leveraging the wealth of experience and resources these companies can provide. In terms of geographical location, industry partners are spread across different regions, with the majority concentrated in the South East (4) and East of England (4). It was challenging to engage industry partners in the evaluation to provide additional information about the impact the research collaboration had on their companies. It is likely, given the early-

[38] EPSRC Centre for Doctoral Training in Digital Health and Care. https://www.bristol.ac.uk/cdt/digital-health/

stage research conducted in IRCs, that these companies were largely in advisory roles rather than participating in the implementation of joint research projects. Therefore, it is unlikely that the partnership has contributed to additional recruitment or generated additional revenues at these key industry partners.

Nevertheless, academic survey respondents consider the new knowledge created by IRCs are relevant to industry stakeholders, including improvements to processes and knowledge transfer activities through collaborations. In a few cases, respondents noted these activities had 'high impact' on businesses. One example is the work conducted at IRC i-sense on Google's Flu Trend algorithm, which may have supported decisions of Google's Health Trends teams moving to London and subsequent impact on UK employment opportunities.

Further funding

No data was available on leveraged cash funding received from these industry partners over the lifespan of the IRCs. Nevertheless, case studies show that in-kind benefits were obtained by IRCs from these industry partners.

IRC researchers also reported £113 million in further funding in Researchfish submissions[39] (Appendix A) and an additional £22 million recent funding via survey responses (Appendix C). These funds were obtained mainly from public sources, with the largest share of the total further funding from the EPSRC (39%) and the European Union (23%), followed by Wellcome (8%), MRC (7%), the WHO (6%), and the NIHR (4%). The third sector provided a total further funding of £16.5 million and the private sector close to £5 million. A breakdown of total further funding reported by IRCs shows that i-sense researchers were particularly successful in leveraging additional funding of £85 million, while Proteus obtained £32 million, SPHERE £14 million, and TeDDy £4 million.

The vast majority of these public grants were to IRC researchers for large-scale collaborative research and development projects. For example,

- Proteus researchers are involved in a new project (£6.1 million) to develop deep ultraviolet light therapies using laser physics technology, for example with cancer surgery[40]
- Proteus researchers received funding from CARB-X[41]
- SPHERE researchers received a grant (£6.1 million) to create a platform that can measure the symptoms of disease (such as Parkinson's) continuously in the patient's home[42]
- SPHERE researchers obtained a Momentum award from the UK MRC to support the UK Dementia Research Institute[43]

---

[39] Researchfish contains self-reported data that IRC researchers submitted linked to their grants. We removed follow-on and Next Step Plus IRC fundings from this 'further funding' analysis. Note that less than a quarter of entries had grant reference numbers where we could cross-validate information with public data, but these accounted for over half of the total funding obtained.

[40] U-care: Deep ultraviolet light therapies. https://gtr.ukri.org/projects?ref=EP%2FT020903%2F1

[41] https://carb-x.org/gallery/proteus-irc; https://www.research.ed.ac.uk/en/projects/proteus-participation-in-carb-x-option-stage-1

[42] Transforming the Objective Real-world measUrement of Symptoms (TORUS). https://gtr.ukri.org/projects?ref=EP%2FX036146%2F1

[43] SPHERE project wins MRC award. https://www.bristol.ac.uk/news/2016/october/sphere-mrc-award.html

- i-sense researchers used a new grant (£4.2 million) to create digital solutions for one-health surveillance of antibiotic use and AMR, and for antimicrobial stewardship[44]
- TeDDy researchers received a Transition Challenge Award from the European Innovation Council (£2.2 million) to support the Vector Bioscience spin-out company to further develop drug delivery platforms based on metal organic framework for RNA[45].

Interviews and desk research pointed to further public and private sector investments specifically to create and grow spin-out companies, which will further exploit the technologies developed in the IRCs, with an overall amount of at least £20 million (see more information below in the 'Spin-out companies' section).

Taken together, IRC researchers were able to leverage the prestigious IRC programme and raise a total sum of over £150 million from public and private funding sources for follow-on research and development projects, that is 2.5 times the overall IRC investment.

Contribution to employment

Over 200 individuals were reported (via survey) to have been involved in the IRC programme, of which at least 100 were hired, as a result of the IRC investment. The majority of survey respondents were also confident that future additional employment in healthcare technologies will be generated in their organisation, as a result of the IRC programme. Note that almost exclusively, these responses were related to recruitments by universities. The two companies that participated in the survey had reported no additional or future employment outcomes. It is important to note these employment statistics are broad estimates and do not provide a comprehensive view of the IRC programme's overall contribution to employment.

Patents

We analysed data from all available sources on patents associated with the IRC programme, showing the extent to which the new scientific knowledge, generated by IRC investment, gave rise to inventions that could be protected.

Overall, up to 17 patent families[46] were directly matched to the IRC programme (Table 4). The majority of patent applications were initially filed in the first five years of the programme, suggesting that key intellectual properties were developed within the early stages of the IRC programme. A breakdown shows that some IRCs focused on advancing research towards future commercialisation through patenting their intellectual property, as exemplified by Proteus with their 11 unique patent families created. In other IRCs, like SPHERE, focus was explicitly not on protecting the new knowledge generated during the research projects. We also analysed the fate of patent applications, which showed that Proteus has already 10 patent applications granted, each for a different patent. In the case of i-sense, out of their four patents, one has been granted in three different jurisdictions, and for the others, patent applications are still pending. These findings are important not only to demonstrate the new scientific knowledge of the IRC programme, but to provide an indication of the potential future economic impact of the IRC programme. This is discussed further in individual case studies (see Appendix).

---

[44] https://gtr.ukri.org/projects?ref=EP%2FX031276%2F1

[45] https://www.strata.team/eic-transition-winners-and-statistics-september-2022/

[46] A patent family is a collection of patent applications covering the same technical content or invention.

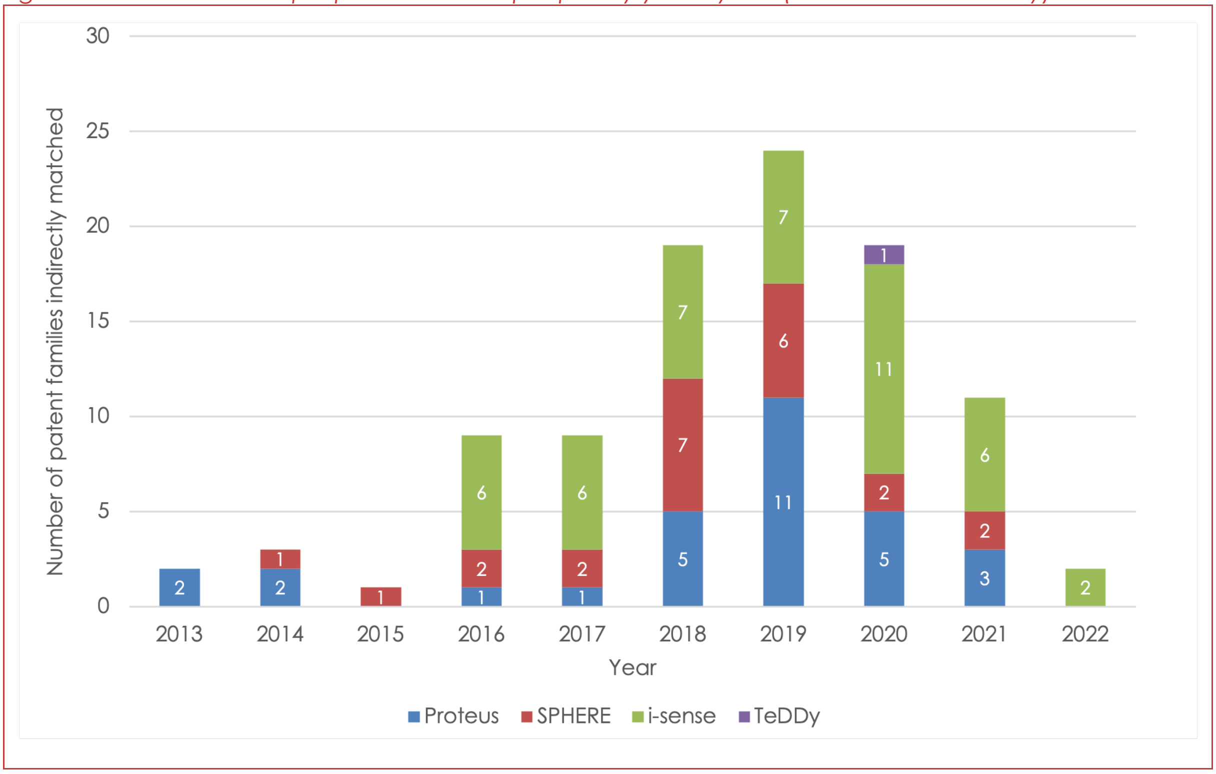
Table 4 Patents and patent applications generated by the IRC programme

IRC name	Number of unique patent families	Number of patent applications granted	Number of patent applications pending	Number of patents applications replaced / cancelled
i-sense	4	3	3	1
SPHERE	0	0	0	0
Proteus	11	10	19	22
TeDDy	2	1	1	0
Total	**17**	**14**	**23**	**22**

Source: Technopolis analysis based on analysis of data from Researchfish and Dimensions, stakeholder consultations *and exchange with the University of Edinburgh Technology Transfer Office.*

Beyond the patent applications directly attributable to the IRC programme, many IRC publications from Proteus, SPHERE and i-sense have informed, and likely contributed to, many other patent applications beyond the IRC programme. Dimensions data includes a further 99 patent families that can be considered indirect outcomes of the programme because these filed patents cite one or more IRC publications (see Appendix B). This 'knowledge spillover' from the IRC programme to other patents and related areas is an important impact of public investment into research and testifies to the research excellence created in these collaborations. The emergence of this 'second wave' of indirect patents from 2016 onwards is shown in Figure 7. It also indicates that IRCs without a strong commercial focus, such as SPHERE and i-sense, have also produced knowledge relevant to patenting activities beyond the IRC programme. Most patents were filed with the World Intellectual Property Organization (WIPO), followed by the US Patent and Trademark Office (USPTO) and European Patent Office (EPO).

Figure 7 Number of unique patent families per priority year by IRC (indirect matches only)



Source: Technopolis analysis based on Dimensions data

Research knowledge, tools and technologies developed in the IRC programme can also inform clinical trials (not funded by the EPSRC) and policy documents published by, amongst other, the UK Government[47], World Health Organisation[48], OECD[49], the European Union[50], The Alan Turing Institute[51] and the Canadian Agency for Drugs and Technologies in Health[52] (examples available in the footnote for illustration). More information is provided on these in the 'Impact on Health and Society' section (3.4) below.

Spin-out companies

The IRC programme has been successful in generating economic impact through the creation of six spin-out companies. Table 5 provides descriptive statistics for these spin-outs in terms of age, region of incorporation, and industry sector.

---

[47] Flu annual report. UK Health Security Agency (2023) https://www.gov.uk/government/statistics/annual-flu-reports/surveillance-of-influenza-and-other-seasonal-respiratory-viruses-in-winter-2021-to-2022#references

[48] Target product profile for readers of rapid diagnostic test. Bull. World Health Organisation (2023) http://dx.doi.org/10.2471/BLT.23.289728

[49] COVID-19 and Science for Policy and Society. OECD Science, Technology and Industry Policy Papers (2023) https://www.oecd-ilibrary.org/docserver/0afa04e2-en.pdf

[50] Improving pandemic preparedness and management. Independent expert report by the Group of Chief Scientific Advisors (2020) https://data.europa.eu/doi/10.2777/370440

[51] Understanding artificial intelligence ethics and safety. A guide for the responsible design and implementation of AI systems in the public sector. The Alan Turing Institute (2019) https://doi.org/10.5281/zenodo.3240529

[52] Internet-Delivered Cognitive Behavioural Therapy for Major Depressive Disorder and Anxiety Disorders: A Health Technology Assessment. Canadian Agency for Drugs and Technologies in Health. (2019) https://pubmed.ncbi.nlm.nih.gov/31246383/

Table 5 Descriptive statistics on spin-outs

IRC	Company name	Description	Age (Years)	Region	Industry
Proteus	BioCaptiva	University of Edinburgh spin-out that has developed a novel medical device for the application of liquid biopsy to diagnose and monitor difficult-to-detect cancers.	5	Scotland	Biotechnology and Life Sciences
Proteus	Prothea Technologies	The mission of the company is to provide a combined endoscopic imaging and biopsy tool for the distal lung to diagnose lung cancer, reducing time-to-treat from weeks to minutes; relieving hospital pressures, and improving patient outcomes.	3	Scotland	Biotechnology and Life Sciences
Proteus	Singular Photonics	An engineering spin-out aimed at developing high-performance camera modules based on sensitive light detectors, with applications in spectroscopy, microscopy, and medical imaging.	0*	Scotland	Industrial, Electric & Electronic Machinery
i-sense	Signatur Biosciences	A spin-out providing smart PCR kits that can detect complex diseases.	2	London	Diagnostic equipment
i-sense	Zyme Dx	A spin-out from Imperial College offering rapid diagnostic tests aimed at achieving earlier diagnoses.	2	London	Biotechnology and Life Sciences
TeDDy	Vector Bioscience Cambridge	University of Cambridge spin-out that has developed a tailored platform technology based on specific porous materials (known as meta-organic frameworks) that improve cancer drugs' efficacy and safety.	3	East of England	Biotechnology research

Source: FAME and manual online searches. Note: *Singular Photonics has been incorporated on 2 February 2024.

We have explored the history, R&D activity and context of the spin-out companies created by IRC researchers. Short descriptions are provided in the boxes below, for Zyme Dx, a spin-out created by i-sense researchers (Box 6), Singular Photonics, a spin-out created by Proteus researchers (Box 7) and Vector Bioscience, a spin-out created by researchers at TeDDy (Box 8).

Box 6 Zyme Dx uses nanozymes to develop and commercialise ultra-sensitive diagnostic tests

While early detection of infections such as HIV is key to successful treatment, the application of lateral flow immunoassays (LFIAs) in early disease diagnostics is often limited due to insufficient sensitivity and the short time frames available for testing. As a result, current LFIA technology cannot detect the low levels of biomarkers present in the early stages of the disease.

In 2016, a team from IRC i-sense set out to develop an LFIA for ultra-sensitive detection of p24, the viral capsid protein of HIV and the earliest biomarkers of infection. The team developed an LFIA up to 20 times more sensitive than the leading commercial rapid tests for p24, giving a signal that can be detected by the naked eye or a mobile phone. To achieve this, the team incorporated two novel approaches – nanozyme particles to amplify the test signal, and nanobodies to optimise binding of the target molecule at the test line. With mobile device adoption continuing to spread globally, this type of test promises to enable access 'for all', including in otherwise resource-limited settings.

The results of the work were published, and the team has continued to improve the nanozyme platform, achieving promising results for the use of nanozymes in diagnostic tests for biomarkers of both communicable and non-communicable diseases. The work has led to two patent applications (currently pending). A spin-out company, Zyme Dx, was created to take the nanozyme diagnostic platform forward into clinical testing and commercialisation. The development work has also received follow-on funding from public and non-profit funders.

Box 7 Singular Photonics develops ultra-sensitive and fast image sensors for pulmonary microendoscopy

Fast and accurate point-of-care diagnostics (POC) play a crucial role in intensive care units as they can detect early complications and thus improve success of interventions. Microendoscopy may be used as a POC for examining lung tissue with real-time video to support surgery and other urgent interventions in critically ill ventilated patients. However, there are several challenges to using pulmonary microendoscopy, including low image quality and harmful side effects.

In 2013, IRC Proteus set out to develop a fibre-based optical sensing and imaging platform (FOSIP) to improve POC for lung diseases. FOSIP required researchers to develop new semiconductor technology for imaging sensors capable of improving real-time video image quality. Between 2013 and 2017, new designs and prototypes of optical detectors were developed, achieving significant improvements to imaging resolution. Proteus researchers also developed the digital architecture and custom firmware for integrating the sensors into POC. This work produced highly cited publications in several fields, including electrical engineering and medical optics; it also enabled FOSIP to be tested in ongoing human clinical trials.

The technology underpinning the new imaging sensors was patented and enabled the creation of Singular Photonics, a spin-out company that will license the patent and seek to use the technology in other medical and scientific applications. The company has attracted interest from market leading companies in the field of high-precision instruments for life sciences and it has obtained pre-seed funding to develop new technologies.

Box 8 Vector Bioscience develops nanomaterials to deliver drugs to hard-to-reach cancers

Current medical treatments have limited therapeutic effect against cancer in the brain and lung, leading to low survival rates in patients. One key challenge is adapting interventions to overcome natural barriers that limit the rate of anti-cancer drug penetration, such as fibrous outer layers in tumours.

In 2018, researchers at IRC TeDDy set out to develop and validate new nanomaterials for drug delivery vehicles, such as metal-organic frameworks (MOFs). MOFs can be used to encapsulate drugs and improve the efficacy of a range of therapies. A new approach to create a modified MOF was developed, presenting delayed drug-release capabilities and lower toxicity when compared to other MOFs. This approach also improved the material's stability, integrity in solutions and enabled dry storage.

The technology underpinning the modified MOF was patented and Vector Bioscience was created as a spin-out company that will license the patent and conduct translational research and development of nanomaterials for drug delivery applications. The company has attracted over £2 million pre-seed funding, which will enable further preclinical and clinical studies to collect toxicity and effectiveness data. Positive results of these studies may lead to new formulation of drugs for hard-to-treat cancer in the future.

All six spin-outs have secured further funding, according to secondary data sources, interview consultations with programme participants, and manual online searches of investment deals. Collectively, the spin-outs have secured 12 deals worth more than £18 million in total. The figures present a conservative estimate, primarily attributed to challenges in acquiring data regarding deal values and the confidential nature of such information. The three Scotland-based spin-outs of Proteus raised £15 million from Venture Capital (including the University of Edinburgh's venture investment fund), business angels and Scottish Enterprise. The two i-sense spin-outs raised undisclosed amounts from Riceberg Ventures and Y Combinator, the NIHR i4i programme award and grants from non-profit organisations. Funding of £2.7 million for TeDDy's Vector Bioscience has come from Innovate UK and investment from the European Innovation Council's 'Transition Challenge' programme. Appendix E provides further details on the investment deals of IRC spin-out companies.

The evaluation aimed to estimate the economic contribution of the IRC funding to spin-outs, in terms of employment creation and gross value added (GVA). Collectively, IRC spin-outs have generated 28 new jobs in total, or five jobs per spin-out on average (Table 6). Based on interview consultations with spin-outs, we understand that all these ventures are in the pre-commercial stages and have yet to report any revenue. As such, we estimated the economic benefit from these spin-outs by multiplying each company's employment figures by the industry specific GVA per unit of employment ratios.[53] By using this approach, we estimated that the 2022 GVA of the spin-outs is around £1.3 million. If employment growth is in line with expectations over the next two years, the GVA derived from IRC spin-outs will grow to £3.4 million.

Table 6 Gross value added estimates of IRC spin-outs

IRC name	Company name	Employment in 2022 *	Projected employment in 2025 **	GVA per workforce job	Estimated GVA in 2022	Projected GVA in 2025
Proteus	BioCaptiva	7	14	£42,316	£296,212	£592,424
Proteus	Prothea Technologies	2	12	£42,316	£84,632	£507,792
Proteus	Singular Photonics	3	12	£42,316	£126,948	£507,792
i-sense	Signatur Biosciences	7	14	£64,635	£452,445	£904,890

[53] Regional gross value added (balanced) by industry, April 2023. Available at: https://www.ons.gov.uk/economy/grossvalueaddedgva/datasets/nominalandrealregionalgrossvalueaddedbalancedbyindustry

i-sense	Zyme Dx	4	8	£64,635	£258,540	£517,080
TeDDy	Vector Bioscience	5	10	£33,992	£101,976	£339,920
Total		**28**	**70**		**£1.3m**	**£3.4m**

Source: Technopolis analysis of FAME and manual online searches. Note: Regional GVA per workforce job in the professional, scientific and technical activities sector; chained volume measures in 2019 money value; and GBP in 2021. * Employment figures that company representatives disclosed or available publicly. ** Projections are from expectations disclosed by interviewees, or estimates based on average anticipated growth.

Wider economic impact

In general, it is too early to assess the wider economic impact of the IRC programme. However, the i-sense project of modelling infectious diseases using web data (Box 10) has already created such impact through its contribution to Public Health England's (PHE) decision to introduce a national influenza vaccination program for children. The novel digital epidemiology technology was able to provide accurate estimates of influenza vaccine effectiveness in pilot studies and, as a result, it has been incorporated in the UK's public influenza surveillance system. It has been shown that childhood influenza vaccination reduces influenza prevalence in the general population by 20%. Considering that the impact of seasonal influenza is associated with a loss of £644 million to the UK's economy (about 4.8 million lost working days), 5,000 excess staff absences per month and longer A&E waiting in the NHS[54], i-sense has already demonstrated that IRC technologies can and do contribute to significant wider economic impact.

In summary, the IRC programme investment of £59.1 million into research in healthcare technologies between 2013-2024 has already achieved notable economic results, despite the fact that the programme funds basic and proof-of-concept research (TRL 1-3) and some of the projects are still ongoing. It is likely that the technologies researched and progressed in the IRCs will continue to advance via follow-on research projects, receiving further funding, patent licensing, and technologies further developed and commercially exploited by the spin-out companies created by IRC researchers. The employment of highly skilled researchers at universities and spin-out companies has started to address skills gaps in healthcare technologies and may act as a multiplier in the future. Nevertheless, it is too early to rigorously assess the economic impact of the programme, with all spin-out companies currently in the setup or pre-commercial phase. While major industry partners have engaged with the IRC programme, during interviews, wider stakeholders pointed to the relatively low levels of industry engagement and slow progress of translation of technologies for practical applications in healthcare. During interviews, some IRC researchers also noted that commercialisation of their inventions is still a challenging undertaking. It is due to difficulties in navigating the patenting process at the required speed through university technology transfer offices, together with the lack of skilled staff and funding available to grow spin-out companies at some geographical locations.

[54] https://www.rand.org/pubs/research_reports/RRA2165-1.html

3.4 Impact on health and society

The long-term goal of the IRC programme is to impact population health and wellbeing by improving individual patient health outcomes and/or enable cost savings in the healthcare system through more effective and efficient interventions. These savings will release resources for use elsewhere in the healthcare system or the wider society.

The route from individual research projects to health impact is non-linear, often takes a long time and needs several synergistic projects for the technology to reach higher TRL levels and be ready for deployment and routine use. A technology developed over a decade may be superseded by other radical innovations before the technology can reach healthcare practice. The ultimate impact may also depend on external factors in the system where research & innovation have limited influence.

An important step from research outputs toward clinical use depends on whether these outputs can provide the necessary evidence (at the right time and format) for decision makers to incorporate findings into new and updated clinical guidelines and policy papers. Therefore, citations of IRC publications in clinical trials and policy papers are an important proxy metric for contributing to future expected impacts.

IRCs do not directly conduct clinical trials as this is beyond the scope of TRL 3 research. Nevertheless, research knowledge, diagnostic tools and technologies developed in the IRCs may contribute to innovative clinical trials and provide evidence for public health. Three examples of clinical trials were identified in the Dimensions dataset through citation of IRC publications: two are linked to Proteus[55] and one to SPHERE[56], where technologies developed by IRCs were expected to be used. According to the ClinicalTrials.gov registry site, these studies were, however, not successful and thus we are unable to report on how IRC healthcare technologies contributed to generating clinical evidence.

In addition, Proteus researchers reported via Researchfish five accounts of early clinical assessments that use technologies developed by the IRC[57]. These include:

- BAC ONE and BAC TWO, 'SmartProbe' imaging agents, were developed to identify bacteria deep in the lung of ventilated patients with adult respiratory distress syndrome (ARDS)[58]

---

[55] Diagnosing Corneal Infection (NCT04230811) an observational study with 120 anticipated participants from the Princess Alexandra Eye Pavilion (Edinburgh, UK); registered in 2020 with status currently unknown.

Coronavirus Induced Acute Kidney Injury: Prevention Using Urine Alkalinization (NCT04530448) an interventional study at West Virginia University, USA that recruited only 3 participants and was thus terminated early.

[56] London Investigation Into diElectric Scanning of Lesions (LIESL) (NCT03302819) an interventional study with 994 anticipated participants and sponsored by Royal Marsden NHS Foundation Trust (UK); registered in 2017, with status currently unknown.

[57] Gateway to Research, under Outcomes, Products Interventions & Clinical Trials. https://gtr.ukri.org/projects?ref=EP%2FK03197X%2F1 and https://gtr.ukri.org/projects?ref=EP%2FR005257%2F1

[58] Exploratory Study of Intrapulmonary Microdosing of Gram-negative Optical Imaging Detection Probe, BAC TWO (NCT02491164) an early Phase-I study; registered in 2015 and completed in 2018 with the actual enrolment of 18 participants at the Royal Infirmary of Edinburgh, no results posted on the registry site. Microdosing of BAC ONE to the Distal Lung (NCT02558062) an early Phase-I study; registered in 2015 and completed in 2018 with the actual enrolment of 14 participants at the Royal Infirmary of Edinburgh, no results posted on the registry site.

- FIB ONE, an imaging agent, was developed that can detect fibrosis in the lung. This was tested using two endoscopic procedures and images analysed: routine NHS equipment and a novel endomicroscopy detection system developed by the research team.[59]
- Diagnosis of eye infections using a novel fluorescent probe[60] to allow clinicians to use specific antibacterial agent.

IRC Proteus uses SmartProbes developed in the IRC along with novel detection systems, to enable future clinical diagnosis of infections in the lung and the eye. They have made a large step in this direction by collaborating with the Aravind Eye Care Hospital in India. The following case study describes how Proteus researchers were able to build an inexpensive but highly sensitive imaging device, FluoroPi, for use in resource-constrained settings (Box 9).

Box 9 A frugal point-of-care system for fluorescent detection of microbial keratitis data

Microbial keratitis (MK) caused by bacteria or fungi is the most common cause of blindness in both developed and developing countries. Current diagnostic methods for MK are time consuming and exhibit a wide variation in their sensitivity and specificity. There is a need to develop highly sensitive and accurate, as well as cheap and easy-to-use, diagnostic approaches to provide timely diagnosis.

In 2018, researchers at IRC Proteus collaborated with the Aravind Eye Care Hospital in India to develop a novel rapid point-of-care diagnostic for corneal infections, suitable for use in resource limited settings. The team demonstrated how "SmartProbes" (microbe-specific fluorescent reporters previously developed by IRC Proteus) could improve MK detection. In 2019, the Next Step Plus project "Photonic Pathogen Theranostics - Point-of-care image guided photonic therapy of bacterial and fungal infection" (PPT) set out to develop a proof-of-concept, low-cost and easy to use fluorescence imaging device (FluoroPi) that could be used in combination with the SmartProbes. The research team also introduced a new approach for preparing MK samples, with implications for developing less invasive sampling techniques in healthcare facilities.

The PPT project enabled researchers to build on IRC Proteus technology and adapt it for use in resource-constrained health systems. The researchers are currently adapting the FluoroPi technology to turn it into a more robust, user-friendly version. The next iteration of the FluoroPi device will then undergo evaluation with clinical samples as part of future validation studies.

We also explored possible impact through published policy documents informed by IRC research papers. The Dimensions dataset included 58 policy documents that cite IRC publications: 51 for i-sense and 7 for SPHERE; no policy documents were identified that cited papers from the other IRCs. The significant number of policy documents citing publications by i-sense suggests that the focus of its research could directly and in a timely manner contribute to healthcare policy development. An example of that is i-sense's computer science work on monitoring COVID-19 outbreaks, contributing to over 20 weekly national COVID-19 surveillance reports in 2020.[61] A case study showcases how a digital epidemiological research that had developed a tool for tracking influenza was pivoted for immediate use as early warning system in the COVID-19 pandemic by public health decision makers (Box 10). The same digital tool was earlier described to have contributed to wider economic impact through PHE's decision to introduce a national influenza vaccination program for children. It has in fact been

[59] Imaging FIB ONE in the Human Lung Using Endomicroscopy (NCT02604862) an early Phase-I study, registered in 2015 and completed in 2018 with actual enrolment of 18 participants at the Royal Infirmary of Edinburgh, no results posted on the registry site.

[60] Rapid detection of major Gram-positive pathogens in ocular specimens using a novel fluorescent vancomycin-based probe, Sensors & Diagnostics (2022) https://doi.org/10.1039/D2SD00061J

[61] The i-sense paper cited in the weekly surveillance report is: "Tracking COVID-19 using online search" first appeared in arXiv in March 2020: https://doi.org/10.48550/arxiv.2003.08086

achieved through health benefits to the general population and cost savings to the healthcare system (societal benefit).

Box 10 Early warning of infectious diseases using symptoms reported online

Surveillance systems are used by public health agencies to obtain early warnings of outbreaks and mitigate the health and economic impact of infectious diseases. To improve surveillance systems, new digital epidemiology approaches have been developed to understand disease activity and outbreaks in real-time. Key challenges for surveillance systems include obtaining data from a large number of individuals and from those who have not sought medical assistance.

Between 2013 and 2019, researchers from IRC i-sense and partner organisations used web search data from Twitter, Bing and other sources to develop new digital epidemiology approaches for estimating infection rates and disease spreading. Their work produced several highly cited publications and contributed to outcomes with significant impact:

- The first ever assessment of influenza vaccine effectiveness using internet data was conducted, which contributed to Public Health England's (now UK Health Security Agency - UKHSA) decision to introduce a national influenza vaccination program for children.
- Dashboards known as the 'Flu Detector' were developed for daily estimation of influenza rates in England. This tool was incorporated into PHE's surveillance system in 2018, becoming the first system of its kind to be adopted by a national health agency.
- Computer models were developed to estimate COVID-19 prevalence, providing accurate forecast of regional infection surges 7 to 10 days before case counts. UKHSA highlighted how the data influenced national level policies and decision-making, shaping response to COVID-19 pandemic.

Policy documents are also tagged in the Dimensions dataset according to research classification schemes (see Appendix B). An analysis of the fields of research shows that significant share of policy documents citing SPHERE's publications are in 'Human Society' (36%) but also in Health Sciences (19%) and Creative Arts and Writing (14%). At the second level field of research, policy documents are associated with 'Policy and Administration' (43%) and Health Services and Systems' (21%). Examples include two policy documents from the Alan Turing Institute about ethics and safety of artificial intelligence, and AI in financial services. These examples also provide an indication of how SPHERE may impact policy beyond healthcare. For i-sense, the main field of research associated with policy documents was 'Biomedical and Clinical Sciences' (48%) and 'Health Sciences' (23%), and the second level 'Clinical Sciences' (47%) and Health Services and Systems' (15%). Examples where i-sense publications are cited include the Flu annual reports from the UK government[62] and a target product profile (TPP) for readers of lateral-flow rapid diagnostic tests, published by the World Health Organisation (WHO)[63].

Further analysis of Researchfish, interview data and targeted research revealed that the other IRCs also contributed to policy development, even if not through referencing IRC publications directly. TeDDy's principal investigator Professor Malliaras contributed with his expertise to the Regulatory Horizons Council's work on the regulatory reform of neurotechnology (methods and devices that interact with the brain and the nervous system). The Council's recommendations were published in 2022[64] and it is hoped that it will contribute to the safe and rapid

[62] Annual Flu report: winter 2017 to 2018, 2018 to 2019, 2019 to 2020. https://www.gov.uk/government/statistics/annual-flu-reports

[63] Target product profile for readers of rapid diagnostic tests. WHO. (2023) https://www.who.int/publications/i/item/9789240067172

[64] The regulation of neurotechnology. Regulatory Horizons Council (2022) https://www.gov.uk/government/publications/regulatory-horizons-council-the-regulation-of-neurotechnology

development and commercialisation of novel neurotechnologies. Several contributions of Proteus to policy impact were reported through Researchfish, but it was not possible to cross-validate those from public sources.

It is likely that IRC technologies will lead to future impact on health and the society with further R&D progress in the coming years. Indeed, one quarter of survey respondents noted that their research had already led to changes in healthcare policy and practice and an additional 60% of respondents indicated the research conducted in the IRCs is likely to lead to changes in policy and practice based on the significant progress that had been made to accelerate translation of their technologies (Appendix C).

SPHERE's multi-modal multi-sensor technology holds promise for future health benefits by detecting Parkinson's disease earlier based on data collected in people's home and thereby allowing earlier targeted interventions (see Box 11).

Box 11 The use of multi-modal multi-sensor technology to measure symptoms and activities of living with Parkinson's disease

Parkinson's Disease (PD) is the second most common neurodegenerative disease in the UK, damaging nerve cells in the brain over many years and leading to a reduction in the neurotransmitter dopamine and related control of body movement. It is therefore essential to develop ways to detect the disease and intervene at the earliest disease stage. A key challenge is that current practice requires clinicians performing standardised tests at monthly "snapshot" assessments rather than having access to the patient's real-world symptoms continually.

In 2018, researchers from IRC SPHERE set out to study how SPHERE's multi-modal multi-sensor technology can be used to measure symptoms and activities of daily living with PD. Led by a clinician specialised in neurology, the project sought to find alternatives to the current clinical assessment tool. For five days, 12 participants with PD and 12 healthy control participants stayed in the SPHERE House in Bristol, where video cameras captured participants' daily routines. The study (called PD SENSORS) produced several key research results:

- Developed new mobility-related parameters from real-world data that may be used as digital biomarkers of disease progression in PD.
- Demonstrated how video data can be used to evaluate disease severity when analysing motor activities, such as standing up and sitting down.
- Highlighted the importance of real-world observation of people's day-to-day life patterns as data showed that clinicians' presence can influence patients' mobility outcomes.

The research team has secured follow-on funding of £6.2 million from the EPSRC to take the protocol, findings and results of the PD SENSORS study into a new project called "Transforming the Objective Real-world measurement of Symptoms" (TORUS), to support generation of data relevant to clinical trials.

Finally, it is notable that the large number of engagement activities by IRCs (500+) contributed to disseminating research knowledge to patients and the public. This helps to boost public understanding of science, and is expected to increase the willingness of the public to participate in future clinical trials and be available for co-design and co-produce research studies.

For example, SPHERE researchers and programme managers invited the public to SPHERE's Smart House at the 'We The Curious' regional science centre in Bristol. Over a five-month period, over 4,700 people tested the demonstration, undertaking activities in the Smart House and generating data to the research project. Participants were also given an opportunity to provide their opinions around data management topics such as data sharing.

In 2017, researchers and programme managers at Proteus created a teaching tool named 'Circuits!' (with co-funding from the Royal Academy of Engineering Ingenious Grant) to facilitate learnings around bioengineering and health[65]. The tool has been embedded into the Scottish curriculum to teach high school students about bioengineering applications in health and inspire the next generation of bioengineers. It has also been showcased and used by school pupils in Rwanda[66]. Another example from Proteus is the 'Our Health Interdisciplinary Research Programme' that aimed to reduce health inequalities by working with socio-economically disadvantaged students from the University of Edinburgh as part of the Patient and public involvement and engagement (PPIE) activities (Box 12).

Box 12 Our Health Interdisciplinary Research Programme: Exploring community-based participatory research

Patient and public involvement and engagement (PPIE) is important to ensure that research projects address issues that matter to patients and the outcomes of the research can make a difference to their lives. However, researchers often do not know how to engage effectively with patients.

In 2017, Dr Helen Szoor-McElhinney launched the 'Our Health Interdisciplinary Research Programme' (Our Health) as part of the PPIE activities of IRC Proteus at the University of Edinburgh. 'Our Health' is a community-based participatory research (CBPR) programme that aims to reduce health inequalities by improving health research skills and knowledge within socio-economically disadvantaged communities, working with undergraduate and postgraduate students from the University of Edinburgh who benefit from learning from a CBPR approach. 'Our Health' initially launched two interdisciplinary, community-based research pilots projects focused on research questions that had been co designed by local patient support groups. These projects involved volunteers from community partner organisations, as well as undergraduate and postgraduate students from the University of Edinburgh, supported by academic experts.

The 'Our Health' programme led to five new partnerships with community partners and further funding to continue activities. As a result of the success of the programme, In 2023, 'Our Health' was developed into an interdisciplinary research undergraduate course called "Sensing in the Community", where students learn about the role of community engagement and carry out interdisciplinary research projects that address real-world issues. The undergraduate course is currently offered by the University of Edinburgh.

3.5 IRC programme implementation

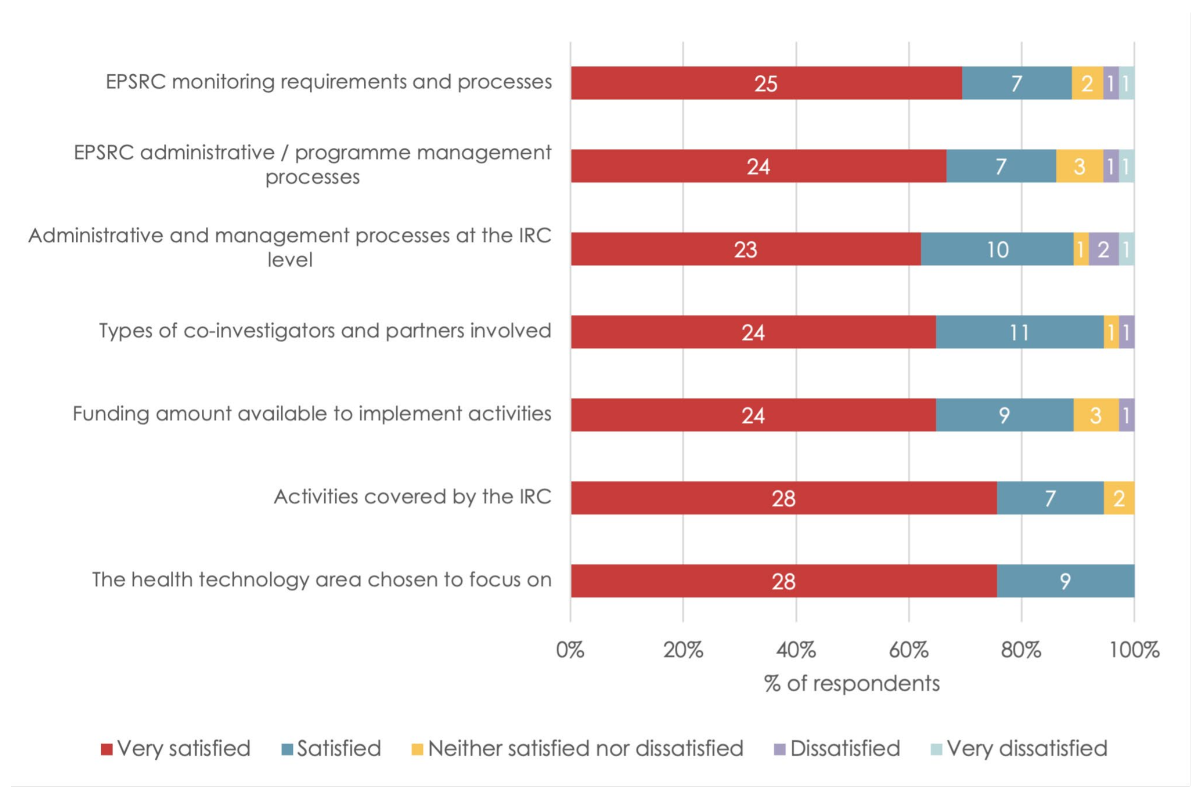
Having reviewed the outcomes and impact of the programme, we turn to the processes by which the research endeavour was implemented and operationalised. This is a useful exercise to understand if the mechanism through which the programme is delivered is fit for purpose, contributed to efficiency in achieving outcomes and impacts, and whether there are ways to improve future funding models and programme design.

We asked IRC researchers the extent to which they were satisfied with various aspects of the IRC programme design (Figure 8). A very large majority of survey respondents (over 80%) were satisfied with all aspects of the programme, including monitoring, administrative and management processes. The scale of funding, activities implemented, research focus and partners involved in the IRC were also rated very highly.

[65] Circuits! - Demonstrating the use of optical fibres in biomedical sciences. (2019) https://doi.org/10.7488/ds/2587

[66] https://www.ed.ac.uk/inflammation-research/news-events/2017/proteus-ingenious-project-circuits-rwandan-school

Figure 8 Participant satisfaction with the design of IRC programme



Source: Online survey results with IRC programme researchers

In the following sections, we discuss the key topics emerging from surveys and interviews with IRC researchers and wider stakeholders.

Programme design

Interdisciplinary Research Collaborations, by definition, aim to tackle large societal challenges by researching and developing innovative technologies at the interface of engineering, physical and biomedical sciences. The Healthcare Technologies IRC investment aimed to match the scale of the challenge with funding that has a larger size and longer timeframe than usual projects applying for responsive mode grants (offering £9 million to £11 million over five years in the first round for each of the three collaborations). IRC leads have confirmed that this level of funding was a key strength of the programme and set it aside in the UK funding landscape. It created a 'buzz' and attracted researchers and engineers of the highest quality from different (often non-health) backgrounds, to compete for research funding in sensing systems for healthcare technologies. This level of grant has allowed large consortia and partnerships to form, tackle the challenge of building critical mass and breaking disciplinary siloes, and to test disruptive ideas freely.

The call text (published in 2012) was relatively open in terms of the specific challenge and healthcare technology to research, but provided guiding principles to applicants: focus on research excellence and building critical mass; engagement with new academic partners, industry, clinical/user expertise and policy makers; using novel and innovative approaches and contribute to the development of relevant, usable and scalable healthcare technology platforms. The call text for targeted therapeutic delivery (published in 2017) was different in the sense that it followed a dedicated workshop on the topic and the call was delivered by EPSRC in partnership with two large UK pharmaceutical companies who formed part of the assessment panel. The call texts also required that 10% of the total grant value was dedicated to a Partnership Resource Fund (PRF), to bring in new partners relevant for the stage and progress of the research over the lifetime of the award.

Partnership Resource Funding was highlighted by all IRC leads as an important element that enabled them to grow their network of partners and programme. The IRC network expanded from 30 organisations in the first funding period (2013-2018) to 73 organisations in the second period (2018-2024). Two thirds of these latter organisations (57 including the IRC Teddy) were new to the IRC network. In total, 87 distinct organisations were involved in the IRC programme over the 10-year period. It was noted by an IRC lead that PRF also represented a substantial administrative burden to draft and sign many contracts, requiring a large administrative team and contributing to delaying some new projects. For more details on PRF, see Box 13 and Appendix on Case studies.

Box 13 IRC programme's Partnership Resource Fund

Building critical mass in healthcare technologies involves gathering relevant expertise and resources to accelerate research and innovation. The Partnership Resource Fund (PRF) is a flexible funding mechanism of the IRC programme which required that 10% of total IRC grant value was allocated to activities for bringing new partners onboard and funding pump priming activities. At the start of the IRC Programme, each IRC outlined a plan for implementing PRF, including workshops to identify new partners and funding for new research projects to generate data or demonstrate feasibility.

In the case of IRC i-sense, the management team set up a dedicated board for managing PRF in 2013, and allocated, beyond the required 10% of the IRC grant, an additional 20% to fund small and high-risk projects ('Exploratory Projects'). The aim was to grow i-sense into a self-sustained hub of innovation, by building networks of excellence with external academic, clinical and industry partners. A total of 12 exploratory projects were funded through three rounds of internal competition, in which universities of the i-sense consortium could bid for funding ranging from £70,000 to £140,000. Under the PRF and Exploratory Projects umbrella, several other activities were conducted at i-sense, including themed workshops with experts, Knowledge Transfer Grants for translating technologies into products and practices, and 16 Mobility Fellowships awarded to researchers to work at other (international) institutions.

Overall, the PRF provided flexibility to IRC management teams to be agile and establish new collaborations, contributing to the expansion of the IRC programme network. In total, 87 distinct organisations were involved in the IRC programme over the 10-year period. Over half of these organisations are UK universities and research institutes, and about 15% are industry. Companies mostly contributed in-kind resources and provided guidance to projects. To illustrate, the PRF enabled:

- New partnerships at i-sense with industry and public authorities, leading to high impact research on digital epidemiology approaches to monitor infectious diseases outbreaks.
- Strengthened SPHERE's ecosystem of digital healthcare research, leading to the creation of a new £6 million Centre for Doctoral Training in Digital Health and Care at the University of Bristol.
- Attracted a large number of universities to the Proteus consortium in 2018, leading to several patents filled in the field of semiconductors and chemical reagents, as well as supported the creation of a Healthcare Technology Accelerator facility based at the University of Edinburgh.

Interviews confirmed that large-scale funding interventions such as the IRCs have the ability of creating critical mass, facilitating interactions across disciplines within the team and beyond, and uniquely help researchers to tackle and overcome difficult technical challenges. It also allows flexibility to adapt the project to emerging findings and pivot when required. Other benefits of large-scale funding programmes mentioned include the prospect of good project governance systems through advisory boards, reduced time spent on frequent funding applications by senior investigators, more attention paid to recruiting and training staff, and job security for early career researchers.

External experts also highlighted that building critical mass in new areas supports institutional adaptation to new societal challenges within universities and creates an ecosystem of partners that enables impact through interdisciplinary research. It was noted that large-scale programmes are often organised in a top-down fashion to build critical mass, which can be effective. However, ground-breaking research also requires a bottom-up approach, driven by researchers' own interests and expertise. Ultimately, there was consensus around the importance of having a mix of a few large-scale project funding and a larger number of smaller project grants.

External experts also noted that large-scale projects may have less defined goals from the outset, which can slow down research progress. Indeed, we heard from an IRC Director that at the start, they had little insight into what specific research they would conduct. Instead, the funding allowed them to explore, together with the public and end user community, the relevant research directions in the first year of the IRC. Nevertheless, to reduce the risk of large-scale research projects pursuing directions which are ultimately not feasible, EPSRC may consider increasing funding for pump priming activities, to gather data and experiences outside of awarding large-scale programme grants.

Governance and monitoring the programme

The four IRCs were conceived by their respective directors with the involvement of their co-investigators, and they had full flexibility in designing and implementing the programme of work. Consequently, the four IRCs were rather different in their setup, focus, management practices, ways of working and progress monitoring arrangements.

IRCs had established their respective Management Committee to ensure objectives of the programme were met. Work package leads formed a Steering Committee and, in some cases, a Public Advisory Group was also established (by SPHERE). All IRCs created bespoke external Advisory Boards to guide and oversee research progress. The EPSRC appeared to have a relatively light-touch role as a funder and were involved as observers in Management Committee meetings.

Reporting was largely conducted by IRCs to their own Advisory Boards (with membership approved by the EPSRC). However, almost no Board meeting minutes were provided to the evaluation team, either by EPSRC or the IRCs (for documents made available, see Appendix F). A formal mid-term review was conducted in 2015/16 for the three IRCs researching sensing technologies, and in 2022 for TeDDy. No mid-term review took place in the second five-year funding cycle, but mid-term progress reports were prepared by the IRCs and made available to the evaluation team. At project closure in 2023, the three original IRCs organised 10-year anniversary events, where presentations summarised notable achievements. The evaluation team was able to attend and observe the final i-sense conference that has seen about 100 students and postdocs return to recount their experiences with the IRC and ensuing career paths.

i-sense also published annual reports[67] that included research highlights, communication and engagement report, publications, information on the Management Committee, Advisory Board, Strategic Advisors, and key industrial and clinical partners. i-sense's extensive central administrative and communication support made internal and external coordination a noticeably smooth process.

The evaluation team did not find evidence that the EPSRC conducted formal milestone assessments at key points during the IRC's 10-year investment period as part of a stage-gate review process, where go/no-go decisions would have been made. However, accountability to the external Advisory Board suggests that critical discussions about milestones and risks did occur between the IRC Management Committee and the Advisory Board.

One IRC lead suggested that capturing programme metrics was useful for successfully managing the IRC, albeit challenging and required additional resources. A clear challenge to the current evaluation of the IRC was the heterogeneity and scarcity of monitoring and reporting information. The format and content of the reports (including monitoring and impact indicators) varied substantially from IRC to IRC, without guidance or template from the EPSRC. It was therefore challenging for the evaluation to aggregate data from these different sources and report at IRC programme level. Nevertheless, annual monitoring information was collected via and made available through Researchfish, providing important self-reported information about the IRCs.

It is noteworthy that the lack of consistent programme monitoring was also mentioned as a weakness by some survey respondents. To enable impact, it was suggested by one survey respondent that EPSRC could have more monitoring and oversight over the programme's milestones. External stakeholders also suggested more focus on tracking milestones and linking the programme with other research infrastructure, such as Centres for Doctoral Training (CDT), may help to maximise the outcomes and potential for impact. This is particularly timely as the EPSRC has recently announced[68] more than £1 billion investment into 65 CDTs, training more than 4,000 doctoral students over nine years in critical technologies such as artificial intelligence and engineering biology.

Ultimately, through survey and interviews, IRC researchers provided overwhelmingly positive feedback about strong leadership, governance and management of their IRC , highlighting the essential role the Advisory Board played thanks to the varied expertise of its members across academia, industry and healthcare. Only a few respondents noted project management challenges around aligning 'research interests' and implementing project resources.

Diversity, sustainability, and future impact

While no diversity data was available for the evaluation to report on, underrepresentation of women in engineering and physical sciences, especially in the large grant portfolio, is a recognised challenge for the EPSRC[69]. It is therefore notable that one of the four IRCs, i-sense, is led by a female director, which is a first in the history of the EPSRC IRCs. The focus on diversity

[67] i-sense EPSRC IRC annual reports. https://www.i-sense.org.uk/research-and-training/our-annual-reports

[68] https://www.ukri.org/news/1-billion-doctoral-training-investment-announced/

[69] Gender diversity in our large grant portfolio. UKRI. https://www.ukri.org/what-we-do/supporting-healthy-research-and-innovation-culture/equality-diversity-and-inclusion/epsrc/gender-diversity-in-our-large-grant-portfolio

and empowering women to become leaders was tangible in the implementation period of i-sense's research programme: from celebrating women[70] in STEMM (Science, Technology, Engineering, Maths and Medicine) to developing the Rosalind Franklin Appathon for Women in STEMM[71]. The survey responses included calls for increasing the diversity (namely women in leadership positions) further.

Diversity also means that the focus of research concerns topics that are of particular relevance for minority groups and other people who do not traditionally participate in research. This type of research contributes to reducing health inequalities and better health outcomes for all. There have been relevant examples from IRC research, including exploring ethical aspects of data collection and use in research (SPHERE) and developing technologies for applications in resource-limited settings in LMICs (Proteus, i-sense). It was suggested by IRC researchers that future funding programmes include considerations around ethical and social issues, as these areas are often neglected in engineering science research projects.

Achieving sustainability for the interdisciplinary collaborations in healthcare technologies is a declared objective of the IRC programme. The evaluation has indicated that new collaborations have been established by the programme that, according to two thirds of survey respondents, have continued (or will continue) beyond the IRC programme. Further funding of over £150 million from a mix of public and private sources for follow-on research and development projects of IRC researchers in academia and spin-out companies, will ensure financial sustainability of retaining and training more research staff. The new Centre for Doctoral Training at the interface of health sciences and engineering/computing in Bristol will also ensure that the knowledge generated by SPHERE will fall on fertile ground. The IRC programme has therefore made significant progress toward creating a sustainable research ecosystem in healthcare technologies in the UK.

The research from the IRC programme will continue to contribute to and generate future impact in research knowledge, leadership in healthcare technologies, skills for UK R&D capacity, and economic and societal impact. IRC researchers expressed that the scale of the programme was necessary to create a critical mass in healthcare technology expertise to solve complex challenges, from tackling infectious diseases to delivering targeted therapies for hard-to-treat cancers. In comparison to other funding programmes, the IRCs have already broken silos between disciplines and accelerated research underpinning translation of medical devices, diagnostics and other technologies for healthcare challenges. Without a decade of IRC funding since 2013, IRC researchers felt that technical progress in their research area would have been limited in scale or executed more slowly with less interdisciplinarity. In some cases, engineers from non-health background stated they would not have joined a collaboration and worked on technical solutions relevant to healthcare.

The flexibility of the IRC programme guidelines and diversity of leadership styles meant the implementation was very much adapted to the objectives of the IRC. In some cases, an IRC has focussed on building a single core piece of technology where the critical path required a degree of 'centralisation', whereas in other cases, research activities were more distributed among partner organisations, allowing for autonomy and collaboration across connected themes. We are aware that in some rare cases this led to tensions around researchers' interests

[70] i-sense Annual Report 2018

[71] https://www.i-sense.org.uk/case-study-rosalind-franklin-appathon

and priorities. This open structure of the IRC programme could thus represent a real risk to the funder, and therefore extended scrutiny of both technical and leadership skills of future leaders of such large EPSRC grants are warranted.

In March 2023, EPSRC's new large-scale funding call was announced for multidisciplinary research and partnership hubs for health technologies[72]. The new funding provides six-year long grants, each for a maximum award value of £12.5 million and starting in 2024. The three targeted health challenges, which are aligned with the recent EPSRC health technologies strategy[73], are: improving population health and prevention, transforming prediction and early diagnosis, and discovering and accelerating the development of new interventions. It appears, therefore, that most of the principles and design features of the IRCs are retained in the new research and partnership hubs. Nevertheless, the focus on a named lead for each of PPIE and partnership working and translation and impact indicates a more determined effort to achieve better engagement and co-creation and co-delivery of the research programme.

4 Conclusions and Recommendations

The EPSRC funding to IRCs represented a high risk[74] and potentially high reward investment. The commissioned independent evaluation collected output, outcome and early impact data to test the hypothesis of the logic model of the intervention and assess the extent to which objectives have been met and benefits have been realised. While the four IRCs had their bespoke technological focus areas, they aimed to achieve the same high-level goals of the programme.

Building critical mass. The scale of IRC investment enabled the attraction of exceptional talent to lead and collaborate on the four IRCs in healthcare technologies, spanning a multitude of disciplines involving engineering and physical sciences. It has built a unique capacity for the future by training over 150 early-career and mid-career researchers through various skills and career development activities and creating a network of 110 established researchers in the UK. The convergence of expertise at this scale around shared interests, goals and vision has enabled the development of new sensing technologies and drug delivery systems for cancer. This was made possible by institutional support and existing infrastructure at collaborating partner organisations. It is likely that a much larger number of researchers will benefit from the programme in the future through the multiplier effect of upskilled and established IRC researchers.

Developing partnerships. The IRC programme created an initial network of 30 organisations in the first funding period (2013-2018) and expanded it to 73 (mostly new) organisations, now including TeDDy, in the second period (2018-2024), to solve specific challenges in healthcare technologies. A Partnership Resource Fund was established within IRC grants that was particularly useful in bringing new UK partners into the collaboration and supporting new joint activities by providing pump priming, as and when needed during the lifetime of the IRCs. Over

---

[72] Research and partnership hubs for health technologies. https://www.ukri.org/opportunity/research-and-partnership-hubs-for-health-technologies/

[73] EPSRC health technologies strategy. https://www.ukri.org/publications/epsrc-health-technologies-strategy/

[74] EPSRC IRC funding may be high risk due to two factors: (i) low TRL scope of the funding (i.e., the science/technology may hit a roadblock or be superseded, and (ii) large funding size to individual PIs (i.e., operational implementational risks).

half of these organisations were UK universities and research institutes. However, these partnerships also aimed to bring skills and expertise from industry and include the perspectives of end-users (clinicians and patients) and policy makers. The evaluation team could not directly engage these additional stakeholders, but an analysis of co-publication data pointed to rather limited (<5% of all publications) involvement in research implementation by industry, government and health facilities. The share of IRC co-publication with international authors was significantly higher at 30% of all IRC publications, which indicates international leadership in healthcare technologies. It is likely that the additional stakeholders provided guidance and in-kind contribution to research projects to enhance their relevance, but the modest size of the pump priming budget (approximately £100,000) was insufficient to convince industry partners to start a joint (low TRL) project with academia.

Enabling translation to products and practices. The diversity in the types of partners beyond academia was expected to enable and accelerate translation to eventual products or practices. The IRC programme was particularly successful in developing and progressing technologies of healthcare relevance, thanks to the interdisciplinary research excellence that could tackle large scale and complex challenges. The case studies developed in the evaluation (and summarised in boxes throughout the report) illustrate the breadth and depth of these innovations and inventions. Patents have been filed, spin-out companies have been created and investments have been raised on the back of these technological advances. These cover sensing systems for prediction of infectious disease dynamics, new diagnostic technologies for clinical environment and resource limited settings, and monitoring disease symptoms in daily life by multi-sensor technology. Targeted drug delivery using various innovative approaches have also advanced, albeit integrating these into a synergistic system was not viable. The core IRC also supported related research through the Next Step Plus projects. In some cases, these were able to progress specific technologies beyond TRL 3 and be applied in fields beyond healthcare (spill over effects).

Informing the research landscape. IRC directors were expected to engage as a group with the EPSRC and help to create a strategic vision for the national research landscape. There was no specific information shared regarding this joint activity during the evaluation. Nevertheless, the policy outcomes in Researchfish submissions provide a rich source of instances where IRC directors and co-investigators individually contributed to high-level discussions shaping national policies on various aspects of the national research landscape. These include: information governance across the health and care system, deployment of digital healthcare technologies across the NHS, and addressing the importance of long term investment in engineering and physical sciences. They were also members of key committees: the EPSRC Strategic Advisory Team, Advisory Board to the Royal Society Review of UK Research Councils, and Expert Advisory Group National Biosurveillance Network; and presented to the House of Lords Science and Technology Committee. There was one opportunity for the three IRCs (i-sense, SPHERE and Proteus) to meet at an 'all IRC conference' in Bath in 2017. Incidentally, for the IRC mid-term review in 2017, directors of SPHERE and Proteus also acted as members of each other's review board, which likely provided learnings about the other IRC's activities. SPHERE's director was also on i-sense's mid-term review board. No additional cross-IRC events were recorded where IRC researchers shared technical and operational knowledge, or IRC directors as a group contributed to a strategic vision to shape the research policy landscape.

Achieving sustainability. The achievements of the IRC programme are expected to be sustained and grown over time through securing additional funding from a mix of public and private sources. This will ensure that these virtual 'national centres of excellence' will become self-sustaining, and partnerships can continue to collaborate on tackling new challenges. The evaluation has shown that the four IRCs have already raised a total sum of over £150 million from public and private funding sources for follow-on research and development projects, which is 2.5 times the overall IRC investment. A part of this additional funding is specifically provided by funders and investors to create and grow the six spin-out companies from the IRCs, which will further exploit the technologies developed in the IRCs. Another part of this leveraged funding is to create a new EPSRC Centre for Doctoral Training at the interface of health sciences and engineering/computing at the University of Bristol. This training programme will also contribute to achieving sustainability of the IRC investment via sharing the knowledge and tools developed by the IRC and create interdisciplinary skills supply for improved R&D capacity in the UK.

Taken together, the EPSRC Healthcare Technologies IRC programme was successful to a large extent in achieving the stated objectives, in part it has already created results and early impacts that were beyond expectations. The fact that a digital research tool could contribute to mitigating the negative socio-economic impact of the COVID-19 pandemic, clearly demonstrated this potential. The 10-year IRC programme has just completed and much of the benefits for both the wealth and the health of the nation will emerge in the coming years. The MRC and NIHR have recently conducted separate '10 year' evaluations of their translational programmes to obtain a deeper understanding of the impacts generated by their investment portfolio.

In order to maximise future impact of similar large-scale research programmes, the following points and actions may be considered by the EPSRC.

1. Improve the potential for translational impact

1.a Explore and understand better the role 'industry' can play in TRL1-3 research. Currently, low level of meaningful industry engagement was visible in the evaluation. It may be unfeasible for large multinationals to extract value from early stage, proof-of-concept research. Potentially innovative small-size and mid-size companies have different expectations and business models. If the Partnership Resource Fund could provide larger (for example, £300,000 to £500,000) contribution to joint research projects for new partnerships, this may be sufficient for companies to collaborate on high-risk projects.

1.b Explore further funding options for researchers that would help them to progress their technologies towards products and practice beyond project end. It may involve advocating for investment more widely into healthcare technologies as a 'joint programming initiative' and convening interested (public and private) funders to this end. For example, certain healthcare technologies will require clinical trials to collect data on safety and efficacy, but perhaps also on cost-effectiveness through pragmatic trials. Currently, very few trials appeared to test at scale technologies developed by IRCs. Establishing a new (multi-funder) pot can generate the scale of further funding that would be required. Potential co-funders may include the NIHR, Wellcome and Cancer Research UK.

1.c Link IRC spin-outs to dedicated funding agency support. Recent report shows that those spin-outs that receive funding from the British Business Bank and Innovate UK are more likely to succeed[75]. These spin-outs also received higher levels of private 'follow-on' equity capital. Nurturing spin-outs in the UK will help reduce the negative impact of research outputs taken

[75] https://www.ukri.org/news/spin-outs-twice-as-likely-to-succeed-with-funding-agency-support/

abroad for commercialisation. Taking an active role in connecting IRC spin-outs to seed funding via the UK Innovation and Science Seed Fund may also be considered.

1.d Link research projects with the UK Catapult network that provide support to both academia and businesses in bringing research to market quicker. They have specialist programmes to upskill researchers, provide specialist infrastructure, testbed and demonstration environments, among others. However, healthcare technologies may not have a 'natural home' among the current Catapult Centres.

2. Embed the programme better in the training & international research landscape

2.a Encourage researchers to use the large-scale funding opportunity to connect better to the world leaders of the thematic area of interest. Mobility Fellowships were a good example how UK researchers benefit from visiting international organisations to enhance research excellence. It can also contribute to grow the UK's global leadership in healthcare technologies, while recognising the need to protect UK intellectual property[76]

2.b Encourage researchers in funding calls to connect to relevant Centres of Doctoral Training and support nurturing new talents as part of the drive to create improved R&D capacity in the UK. This is particularly timely as the EPSRC will invest into training over 4,000 doctoral students over nine years in critical technologies.

3. Improve the monitoring practices

3.a Develop a core set of common indicators for large-scale programmes, such as the IRCs, through inclusive stakeholder workshops that link to expected research outcomes and cover all objectives. Projects should also record and collect such monitoring data and provide it annually to the EPSRC. These would not only support future evaluations but also provide ongoing formative learning opportunities for project leads. It will be important to strike a balance between freedom of IRC management teams to manage such large-scale investments with more robust monitoring and accountability mechanisms. The NIHR appears to have robust practices where deviations from original agreed objectives need to be justified to the funder or funding can be halted. Therefore, it would be important to agree on clearly defined, time-bound milestones to achieve project objectives, and also metrics to track progress. These could serve to make 'go or no-go' funding decisions for research strands within the large-scale projects.

[76] Trusted research and innovation. https://www.ukri.org/manage-your-award/good-research-resource-hub/trusted-research-and-innovation/

technopolis group

www.technopolis-group.com