UKRI-BBSRC Review of technology development in the biosciences

Biotechnology and Biological Sciences Research Council

Review of technology development in the biosciences

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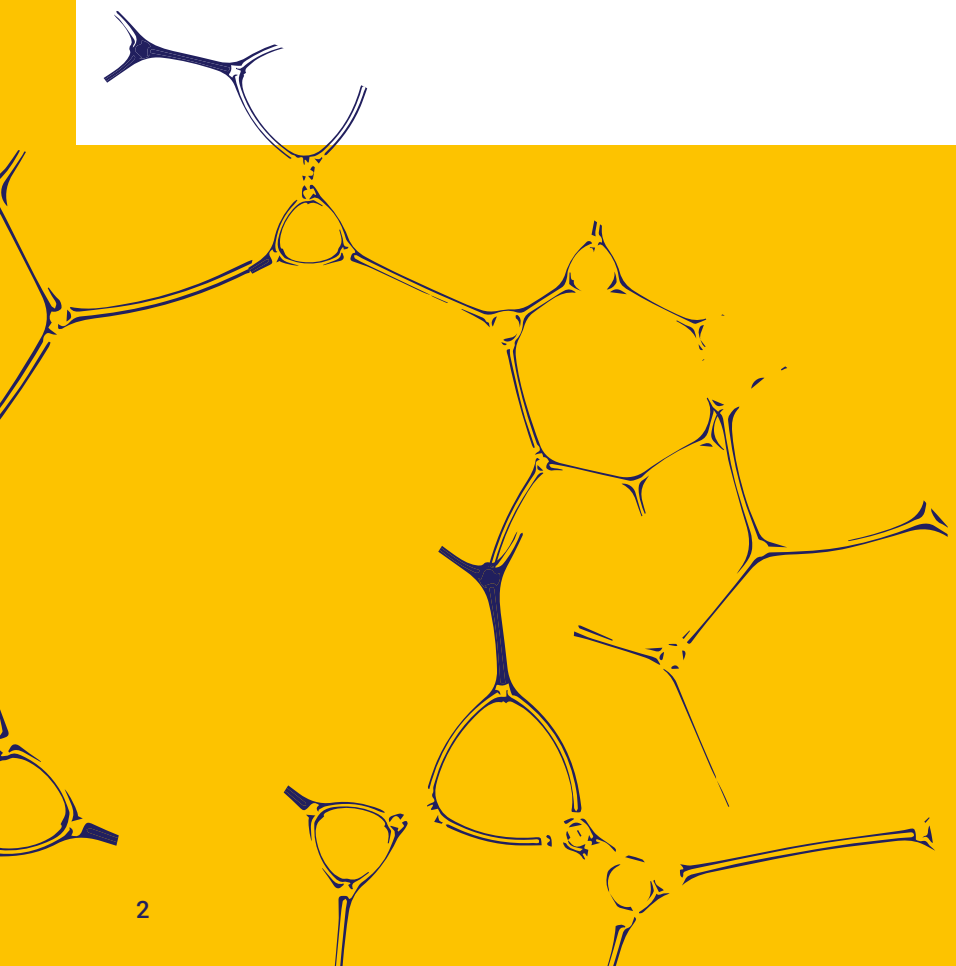


Executive summary

Breakthrough technologies often create a big impact, highlighting the critical dependence of world-class transformative research and innovation on new technologies becoming available.

In 2021, the Biotechnology and Biological Sciences Research Council (BBSRC) initiated a review of technology development in recognition of its crucial importance in the biosciences. The development of transformative technologies is integral in enabling future discoveries as it allows researchers to push the boundaries of bioscience discovery, stimulate innovation and enable better understanding of biological processes and organisms. Support for this area offers significant opportunities to work across disciplines and sectors, to improve on existing technologies and create new ones across the variety of science relevant to BBSRC's mission.

The review found strong evidence for the pervasiveness of technology development across BBSRC's portfolio, but also identified a range of challenges impacting the bioscience community.

An expert task and finish group was convened to help guide and advise BBSRC during the review process. In considering the evidence gathered from our community, 7 key recommendations that aim to support the continued expansion of technology development within the biosciences have been developed:

1. To enable support of the different types and stages of technology development, BBSRC should establish a comprehensive support framework, leading to an increase in investment
2. BBSRC should consider innovation in its peer review processes and fully embed technology development as a recognised and valuable component
3. BBSRC should prioritise short and long-term actions to support different training needs and career stages, with an emphasis on interdisciplinary and innovator skill sets
4. BBSRC should work with the research technical professional community to highlight their talent and promote their central role in technology development in the biosciences
5. BBSRC should promote the value of diversity and team working in the biosciences and foster an open, dynamic, and inclusive system of technology development in the UK
6. BBSRC should consider mechanisms to bring together the technology development communities and facilitate interdisciplinary engagement
7. BBSRC should consider opportunities to support the underpinning infrastructure required for technology development

BBSRC extends its sincere thanks to the research community for the inputs provided and to the Task and Finish Group who guided and advised throughout the review process. The recommendations provide a clear framework to guide our strategy. Our next steps will be to take forward each of these recommendations by developing an implementation plan. Furthermore, we will continue to explore new opportunities to work with other UKRI partners and organisations in order to realise the full impact and benefits that breakthrough technologies can bring.

While some of the recommendations can be addressed through policy or operational change, it is acknowledged that, for others, a significant increase in investment will be required. The evidence from the review will therefore be factored into BBSRC's longer term strategy, forming part of a wider case for increased investment in UK bioscience more broadly.

Background

Introduction

BBSRC initiated a review of technology development in recognition of its critical importance in the biosciences. The development of transformative technologies is integral in enabling future discoveries as it allows researchers to push the boundaries of bioscience discovery, stimulate innovation and enable better understanding of biological processes and organisms. Support for this area offers huge opportunities to work across disciplines, to improve on existing technologies and create new ones across the breadth of science relevant to BBSRC's mission.

Despite the role that technology development plays in the biosciences becoming more important the ever, touching on every aspect of research and rapidly increasing in scope and complexity. The area of technology development and associated support mechanisms within BBSRC have not been robustly reviewed before. The report presents the key findings of the review and 7 high-level recommendations endorsed by a dedicated expert task and finish group. While these recommendations are targeted towards BBSRC, we recognise the broader relevance for and impact on the wider technology development landscape.

Aims and scope of the review

The review prioritises the area of technology development within the BBSRC remit but acknowledges the clear connectivity to other areas of BBSRC interest, including equipment and infrastructure support as well as wider peer review and process considerations. It also acknowledges the inherent inter and multidisciplinary nature of technology development and with it the role of BBSRC as part of the wider UKRI and UK funding ecosystem. All these areas are key parts of the wider landscape supporting technology development, but to retain focus they are not covered in this review.

For the scope of this review, technology development is defined as research and innovation that yields the next generation of new technologies, methodologies, and resources in bioscience, encouraging development of novel bioanalytical or biological tools and technologies where there are gaps. The scope of the review was agreed with the Transformative Technologies Strategy Advisory Panel, part of BBSRC's wider advisory structure.

The review aimed to:

- review the efficacy of the current BBSRC support systems for technology development, including considerations for the complete technology development life cycle
- identify future trends in the technology development space, as well as key community concerns and gaps in the current support system that need to be addressed
- review and propose a range of options to address the identified concerns and gaps, considering all relevant stakeholders in the technology development space for proposed implementation

Review process

Recognising the inherent breadth and connectivity of technology development, it was decided to focus on aspects not yet reviewed recently elsewhere. (Review of data-intensive bioscience and The UK's research and innovation infrastructure: opportunities to grow our capability). The review focused on gathering community input and drew on several lines of evidence, including:

- analysis of BBSRC's funding portfolio and existing strategic approaches to the area
- an open community questionnaire
- targeted follow-on engagement with industry stakeholders via a tailored questionnaire
- targeted follow-on engagement with researchers and innovators at earlier career stages as well as research technology professionals via townhall consultations
- a virtual community workshop to examine key issues highlighted in greater depth with members of the community

In total, inputs from approximately 190 individuals and groups were received as part of the review process, covering a broad range of organisations across the UK.

A small expert task and finish group (page 23) was established to steer the review and provide advice to BBSRC. The group held 4 meetings to develop the consultation approaches, synthesise and validate the inputs received, and agree the key recommendations and final report.

Wider context

Breakthrough technologies often create a big impact, highlighting the critical dependence of world-class transformative research and innovation on new technologies becoming available.

The UK Innovation Strategy highlights the critical need for emerging technologies as 'technological innovation can drive not just incremental but exponential change'. Transformative technologies are key to tackling big, complex societal challenges, but emerging technologies that can make fundamental contributions are equally essential to help shape our lives in the decades ahead. The strategy identifies 7 key technology 'families' where the UK can develop strategic advantage, and which promise transformational benefits for our economy and society:

- advanced materials and manufacturing
- AI, digital and advanced computing
- bioinformatics and genomics
- engineering biology
- electronics, photonics and quantum
- energy and environment technologies
- robotics and smart machines

Several of the identified technology families are directly relevant to bioscience research and innovation, particularly engineering biology, bioinformatics and genomics; artificial intelligence (AI), digital and advanced computing; and robotics and smart machines. It will be key for BBSRC to enable the bioscience community to meaningfully contribute to technological innovation in these spaces.

UKRI's strategy sets out how the 9 councils work together in innovative ways to deliver an ambitious agenda, drawing on our great depth and breadth of expertise and the enormous diversity of our portfolio. UKRI's mission – to convene, catalyse and invest in close collaboration with others to build a thriving, inclusive research and innovation system that connects discovery to prosperity and public good – is key to achieving the highest impact for inherently interdisciplinary areas under its umbrella. Some research and innovation themes by their nature break through council boundaries and require collaboration across disciplines and domains to achieve their full potential. Recently reviewed examples include UK research and innovation infrastructure, and AI.

Technology development is a similarly cross-cutting area that benefits from interdisciplinary approaches and support. Reflecting its pervasive nature, the UKRI Infrastructure Roadmap Programme, the UKRI review document 'Transforming our World with AI' and the National AI Strategy all emphasise the importance of technology development, with facilities seen as hubs to foster and translate technology development and an ongoing need for development to fully unlock the power of AI and data-driven technologies. In its Review of Data-Intensive Bioscience, BBSRC also recognises the need to support innovative data-intensive approaches, methods and software to allow researchers to explore unprecedented research questions leading to major advances in frontier knowledge discovery.

The development of technology is an integral part of contemporary bioscience and an area of strategic interest for BBSRC. In our Strategic Delivery Plan technology development is a fundamental part of the Transformative Technologies theme and underpinning in enabling challenge-driven research. Science research and innovation often involve the development or application of new tools and technologies, including the types of approach that would appear on a biologist's 'wish list' to help address technological gaps, and, increasingly, data-intensive and predictive approaches to biological discovery.

Internationally, the OECD recognised that technology advances can be accelerated and promoted by rapid, efficient and open access to research data, software, algorithms, and scientific workflows. This is especially so during an international crisis, such as the COVID-19 pandemic. The importance of technology is also clear in the UNESCO Recommendation on Open Science. In addition, the OECD highlighted that providing secure, fair, inclusive, legal, and ethical access to research data plays an essential role in enabling the development of AI and other emerging technologies and applications. Development of technology, such as the use of AI is key to unlocking new understanding, value and scientific leads from the enormous quantities and diversity of data available. For example, AI4Good

brings experts together with policy makers, non-governmental organisations and corporates to innovate for the common good.

Technology development for the biosciences

While technology development is present across a range of schemes in BBSRC, some dedicated routes for support have been noteworthy (see also later section on funding support for further detail).

- Tools and Resources Development Fund (TRDF)
- Technology development priority area in the responsive mode scheme

Other technology-focused funding such as the Technology Touching Life (TTL) networks arose from a BBSRC, Engineering and Physical Sciences Research Council (EPSRC) and Medical Research Council (MRC) joint initiative, but administratively they are not directly included in the BBSRC portfolio data. TTL networks aim to support interdisciplinary research at the intersection between the physical and biological/biomedical sciences with a particular emphasis on the role of technologies. The Basic Technologies opportunity is too recent to be included in the portfolio data but highlights the cross-council opportunities for technology development.

An analysis of BBSRC's funding portfolio over the last 5 years, undertaken to understand the effectiveness of the current support system for technology development, revealed a number of insights. The overall investment into technology development has remained relatively stable over the years (Figure 1). While a significant portion of the discussion about technology development investment focused on the Tools and Resources Development Fund (TRDF), the investment is spread much more broadly across schemes including responsive mode (BBSRC standard research grant) and a wide range of initiatives not focused on technologies. Within responsive mode, technology development proposals are far more frequent in Committee C (genes, development and STEM approaches to biology) and Committee D (molecules, cells and industrial biotechnology). Despite some focus in the southeast, the regional spread of investment demonstrates good engagement in technology development across the UK and reflects diversity of view and approach. It also highlights the role BBSRC's strategically sponsored institutes can play in advancing the field. In line with its pervasiveness seen throughout funding schemes and regions, technology development is also cutting across the biosciences with connections to a broad range of research topics within BBSRC. The network plot in Figure 2 gives an indication of the co-occurrence of themes as observed in BBSRC's technology development portfolio.

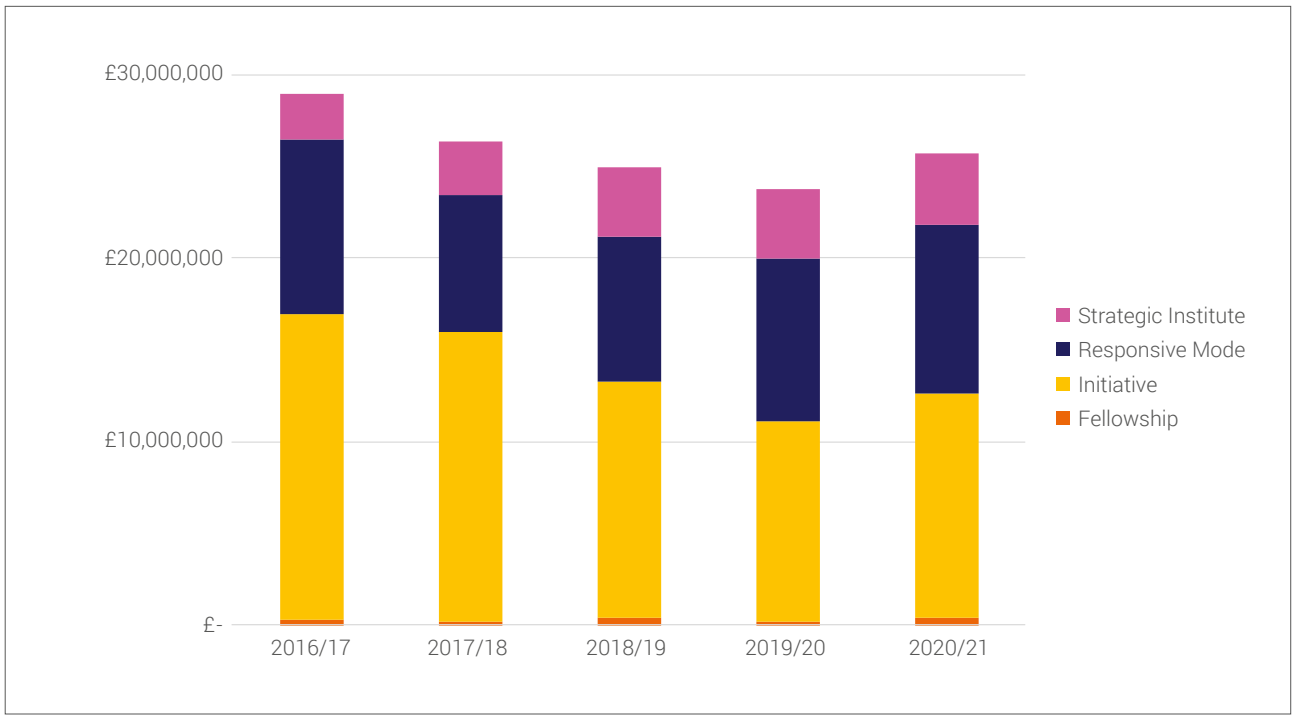


Figure 1: Total spend per year on technology development in the last 5 years, categorised by funding mechanism.

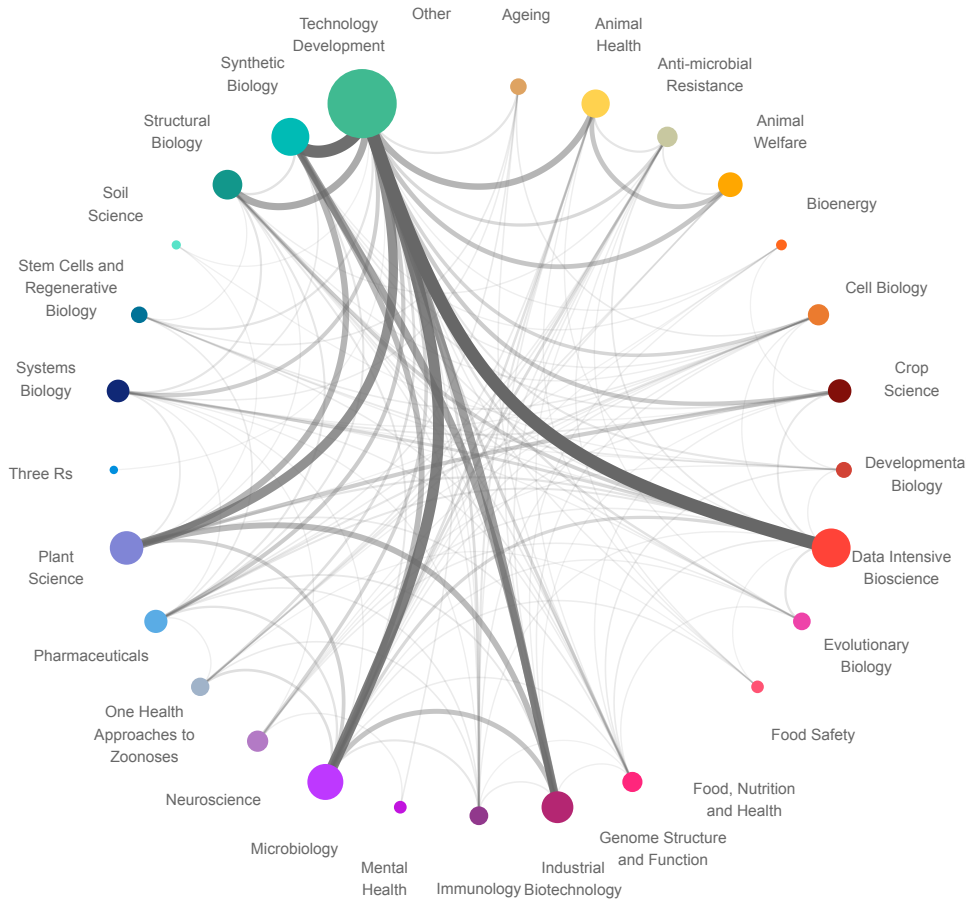


Figure 2: Network plot for 18/19-20/21 highlighting the connectivity between technology development and other research themes within BBSRC remit. The thickness of the connecting lines relates to the extent of the co-occurrence.

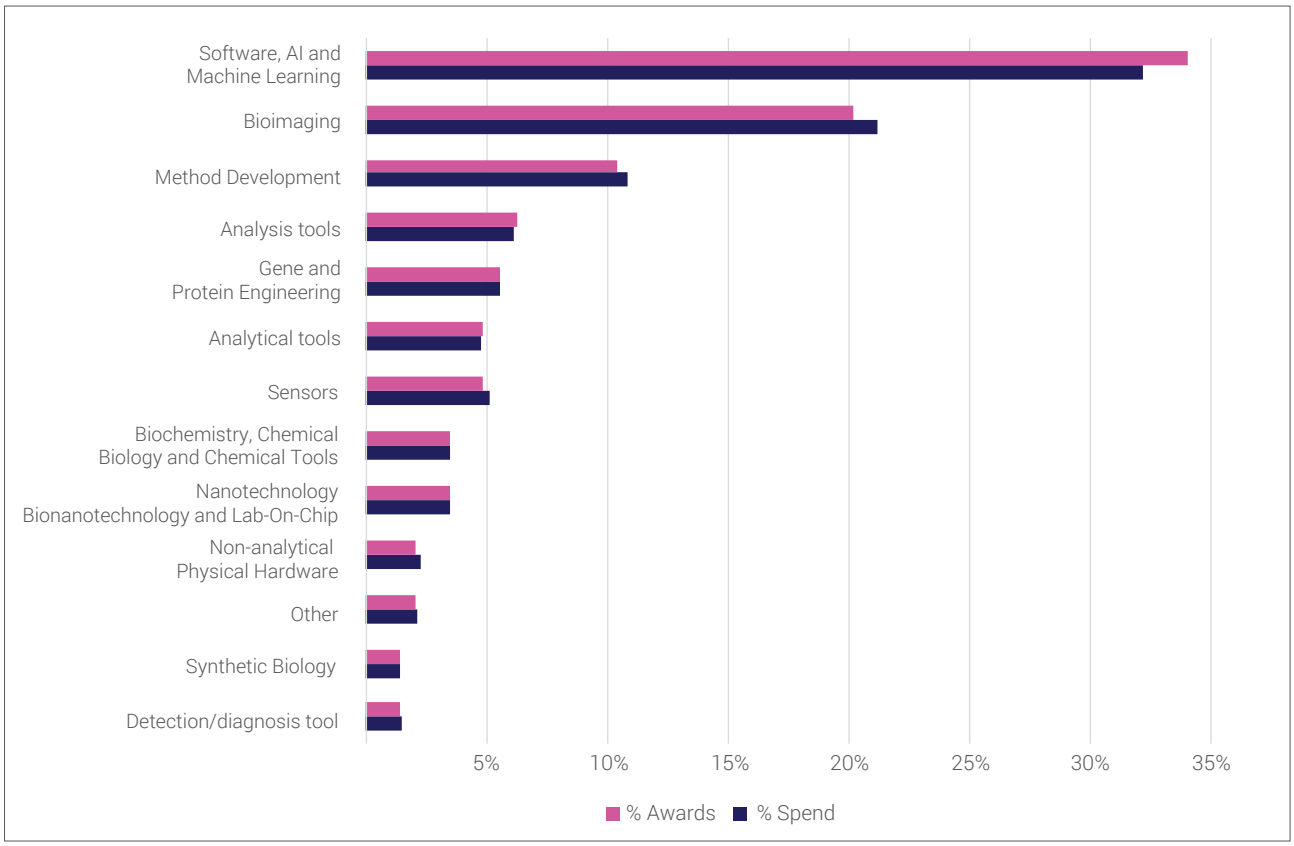


Figure 3: Funded technology development portfolio (with active spend between 2016/17-2020/21) categorised by technology area. The categories are not mutually exclusive.

The bulk of investments support early to mid-stage activities of the technology development lifecycle, a theme also reflected in the community questionnaire responses, where a lack of clarity as well as lack of opportunity regarding later-stage funding opportunities was cited.

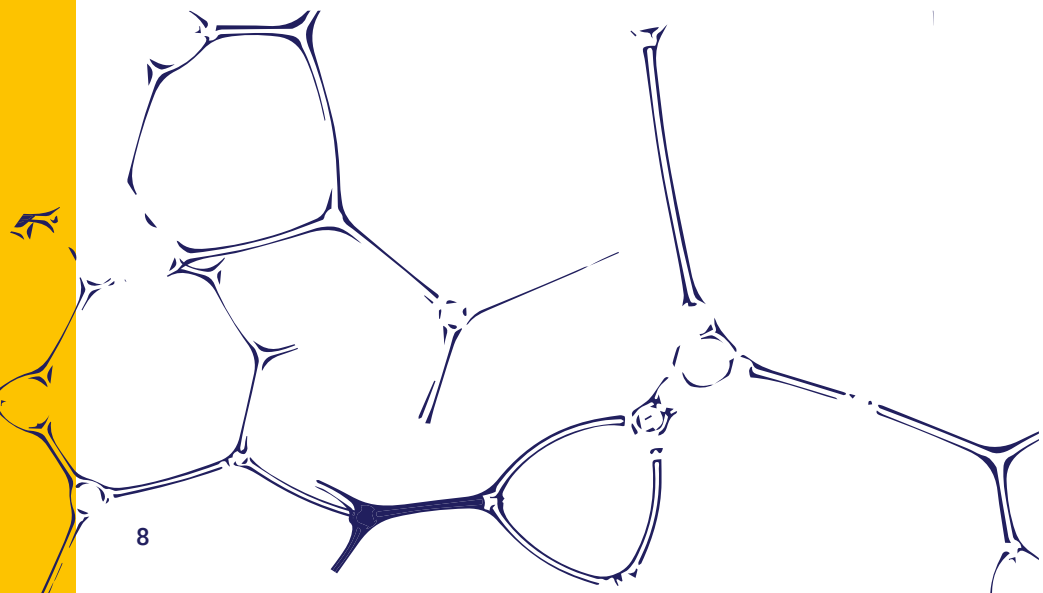
Notably, software-related activities, including AI and machine learning, represent more than a third of the total technology development portfolio (Figure 3). These technology area categories are not mutually exclusive, rather they represent the main focus for each award. BBSRC's overall support for this area shows an increase in investment for software-related activities over time. However, there has been a decrease in the amount of software, AI and machine learning supported through TRDF specifically. This correlates with the consolidation of TRDF into a single funding opportunity in 2016 (previously TRDF 1 wet lab and TRDF 2 in silico) and the associated funding constraints.

Future trends in technology development

The questionnaire and workshop highlighted a broad range of application areas and technologies where the community anticipates technology development will change and impact their sector over the next 5 years. Bioscience has also emerged as a data-rich discipline, and respondents highlighted its increasing significance, which is in line with community observations made as part of the BBSRC Review of Data-Intensive Bioscience. In addition, the application of artificial intelligence to big data in biology is having a significant impact on modern bioscience. Alphafold is a key example of this rapid change. Genomics has very much been seen as the trendsetter with modern sequencing technologies underpinning new possibilities in areas such as spatial genomics.

Respondents understandably saw the improvement of technologies as key to the rapid pace of change in the biosciences. The interaction between the biosciences and engineering and physical sciences is expected to increase hugely. Alongside this there is an expectation that open-source development and making technical developments available via this route will rise, increasing the impact of research as seen with open data. Respondents felt there would also be a trend for the centralisation of skills and hardware resources within institutions. Highlighted was the spread of optical super-resolution microscopy techniques and growing demand for advanced high resolution 3D imaging. Mass spectrometry too was noted as growing in many directions that include advances in the instrumentation, advances in applying it to new topics and translating it out into clinical research. Other key underdeveloped areas for the future were the interface between physics and biology and novel tools to replace the use of animals.

COVID-19 showed there is a need to be able to harness our ability to rapidly change, improve and adapt technology. In addition, there was a clear theme that sustainability and energy use were crucial issues going forward. More broadly, there was an emphasis on smartness of technology development increasing, including miniaturisation, wearability, user friendliness, affordability, and connectivity. As part of this there will also need to be more focus on fully integrated lab-on-chip approaches, and increasing automation.



Deep learning tool offers new opportunities

Building upon previous work by the Centre for Plant Integrative Biology (supported by BBSRC and EPSRC), Dr Michael Pound, an Associate Professor in Computer Science and colleagues at the University of Nottingham have developed and utilised a transformative deep learning analysis approach, "learned multi-resolution image segmentation" (LeMuR – 2016 TRDF) to produce a flexible, open-source plant root phenotyping tool that can be easily adapted by biologists, without re-writing code, to new laboratory environments and imaging techniques. By inputting their own images annotated through use of a novel simplified user interface, the bioscience community can retrain the tool to improve their results for particular data without requiring deep learning expertise, and subsequently seamlessly share their newly trained tool with the community as a basis for further development.

In the long term, the insight provided by this tool can be expected to lead to the identification of new crop phenotypes, which could help address problems such as soil nutrition or water deficiency by identification of traits that affect root system architecture. New and improved crop varieties can also lead to more stable and efficient food production, which could both lead to improved nutritional content of food and potentially lower food prices, helping to meet the challenge of global food security. Finally, the core design of the tool is likely to find application in the analysis of medical (for example. arterial), remote sensing (for example roads and rivers) and document (for example drawings and sketches) images.

New technology offers insight into virus survival

Through his senior research associate role supported, in part, by a 2019 TRDF grant, Dr Allen Haddrell and colleagues in the laboratory of Professor Jonathan Reid at the University of Bristol have utilised novel controlled electrodynamic levitation and extraction of bioaerosol onto a substrate (CELEBS) technology to better understand how survival of SARS-CoV-2 is impacted after periods of suspension in an electromagnetic field under varied environmental conditions.

Their work has revealed key insights into how environmental relative humidity impacts SARS-CoV-2 survival, with a rapid loss of infectivity observed at lower than 45% relative humidity suggesting that dry air may help to limit overall exposure. The high-time resolution infectivity measurements reported are uniquely accessible to the CELEBS technology and can only be understood once the detailed aerosol microphysics are fully explored.

Understanding the factors that influence the airborne survival of viruses such as SARS-CoV-2 in aerosols is important for identifying routes of transmission and the value of various mitigation strategies for preventing transmission, whilst understanding the impact that airborne transport has on pathogens and the influence of environmental conditions on pathogen survival can inform future implementation of strategies to mitigate the spread of diseases such as COVID-19.

Technology developed to investigate how environmental conditions impact infectivity of respiratory pathogens.

Key findings and recommendations

The following sections summarise the key findings of the review, presented under 6 thematic areas, along with 7 key recommendations for BBSRC as agreed by the expert task and finish group.

Funding landscape

Technology development is integral to contemporary bioscience, and BBSRC has had dedicated funding routes for over 10 years (Tools and Resources Development Fund (TRDF) and the technology development priority area in the responsive mode). Since these dedicated funding routes were introduced, they have been successful within their intended scope. However, the needs of the bioscience community have moved forward and now there is clearly a significant opportunity to do more to support technology development in the biosciences.

Current funding models

In 2006, BBSRC established its tools and resources programme (Box 1/TRDF) with an overarching and long-term aim to support the development and deployment of the tools, technologies, and resources essential to sustaining the vibrancy of UK biological research. TRDF's role, which is funded and established through the tools and resources programme, is to pump-prime the next generation of tools, technologies and resources required by bioscience researchers in scientific areas within our remit. More recently with TRDF, collaboration with MRC and EPSRC has helped to remove barriers for interdisciplinary research and enabled an increased budget.

During the review process, the community highlighted many potential challenges and therefore opportunities for the TRDF scheme. Significantly more impact is possible from TRDF than the current opportunity configuration and thematic highlights allow for, and these are ultimately limiting the impact of BBSRC's investments in technology development through TRDF. The opportunity text for TRDF needs to be clear about TRDF's role, eligibility (including for technical professionals) and be supportive of equality, diversity and inclusion. This will help to ensure the diversity of the bioscience community is reflected in the variety of proposals and teams funded by TRDF and the wide range of early-stage ideas that are funded. In addition, the overall framework to support the further development of a technology after a successful TRDF pump-priming project needs to be clear to the bioscience community. Technology development is an area full of exciting ideas, and TRDF's role within that is working well, but BBSRC needs to make the bioscience community aware of all the various avenues where technology development can be funded beyond TRDF. This links with a recognition that supporting technology development can be incremental, rather than always being novel and step changing as required by TRDF. These themes are also reflected more widely throughout the recommendations of this review.

In responsive mode, the **"technology development for the biosciences"** priority area was designed to encourage applications providing tools and resources of potential application to broad communities in the biosciences responsive mode. The Cross-Council Remit Agreement governs how applications that cross two or more council remit domains are managed. The agreement should encourage interdisciplinary applications and ensure equal opportunities for funding. Despite this, the community still noted better integration for technology development within responsive mode is needed.

Both TRDF, responsive mode and other BBSRC funding opportunities support parts of the life cycle of technology development. However, there is a broader range of activities that need to be supported for technology to be developed across its lifecycle; from pilot studies directed towards the development of basic, breakthrough technologies, through to its pump-priming for further development, maintenance and refinement that will enable its later deployment and commercialisation. Mechanisms to support the development of basic technologies through the emerging technologies spectrum also support the careers of research technology professionals.

Future needs and opportunities

A significant and holistic increase in the level of resources dedicated to this area is needed to meet both current and expanding future needs. Future funding support should focus on the sustained expansion of dedicated funding opportunities across all stages of the technology development lifecycle for all types of technologies. BBSRC should carefully consider how funding can accommodate the whole range and pathway of activities, recognising the differing nature of work needed at each stage as well as the key gaps in the current landscape. Supporting this matrix approach would help ensure democratisation of technologies and that technology development for the biosciences can reach its full potential.

A range of options were suggested for better integration of technology development, including but not limited to:

- dedicated funding to bring together problem owners and solution providers for example, shorter, small-scale, and agile support such as business interaction vouchers aimed at supporting academic-industry engagement at the ideas stage
- longer duration and increased funding per award to mediate sustainability concerns and enable support for multidisciplinary teams
- renewal options for successful projects to facilitate continued development
- training in particular technical skills
- short-term visits and longer sabbaticals to enable knowledge exchange
- networks and industry clubs to facilitate collaboration

The technology development landscape is complex, and the funding approaches to support the area should ideally be able to support this complexity in a comprehensive and holistic way. A thread of technology development should also be weaved through BBSRC's existing and ongoing funding opportunities, to help towards bringing an overall structure that reflects the different types and stages of technology development, along with the career paths of research technology professionals.

Recommendation 1: To enable support of the different types and stages of technology development, BBSRC should establish a comprehensive support framework, leading to an increase in investment

Box 1: Tools and Resources Development Fund (TRDF)

'To pump prime the next generation of tools, technologies and resources that will be required by bioscience researchers'

2006 - 2010: TRDF established and held annually using a 'fast track, light touch' assessment process.

2011 - 2013: The initiative was split into two funding opportunities with a budget of around £2 million each annually (total £4 million). Technology and methods development (TRDF1) and Bioinformatics and computational approaches (TRDF2). In 2013 the available project size (80% fEC) was increased from £120,000 to £150,000.

2014 - 2015: Highlights in veterinary vaccinology (2014-TRDF1) and then Animal and plant health (2015-TRDF1 and 2). These were both non-exclusive highlights.

2016: TRDF had a bioimaging highlight, it was also returned to a single call due to pressures on budgets across all BBSRC activities. Although only £2 million was available for a single TRDF call, BBSRC partnered with and had co-funding from EPSRC (up to £1 million) and MRC (up to £300k).

2017 and 2019: BBSRC continued to partner with EPSRC and MRC, along with significant co-funding with an overall budget of up to £3.5 million and £3 million respectively. The funding opportunities specifically encourage proposals relevant to technology touching life, a cross-council initiative to champion research at the interface between the scientific remits of BBSRC, EPSRC and MRC.

2020: Exclusive highlight for the detection and diagnosis of plant and animal diseases. BBSRC partnered with EPSRC with a total budget of £2.75 million.

388 projects funded across 63 research organisations

£47.6 million invested since 2006 through TRDF

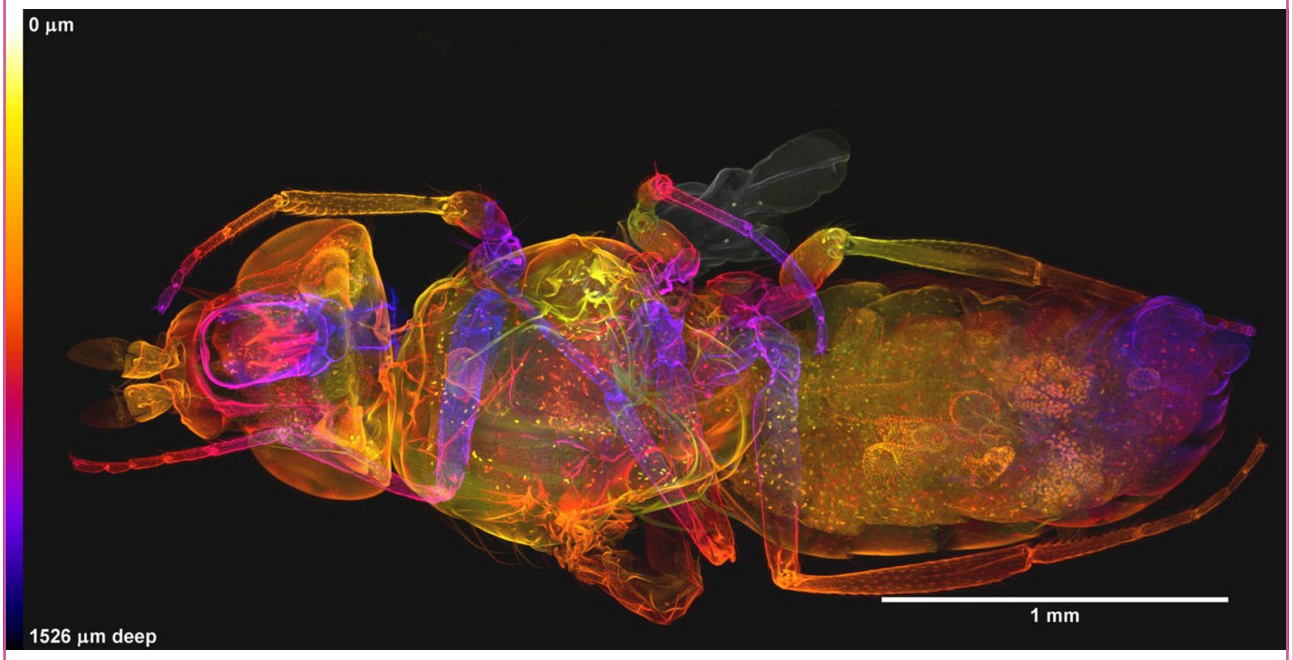
Imaging technology opens new areas of research

"The Mesolab" is an imaging technology centre opened in 2020 in the Centre for Biophotonics at the University of Strathclyde led by Professor Gail McConnell. It provides access to the capabilities of the novel Mesolens technology that enables imaging of unusually large biomedical specimens with the resolution of sub-cellular detail.

The original prototype Mesolens was developed in the Medical Research Council (MRC) Laboratory of Molecular Biology Cambridge (2007), with subsequent support from an Engineering and Physical Sciences Research Council (EPSRC) Knowledge Transfer Agreement Funding as well as the University of Strathclyde enabling Professor Brad Amos to form Mesolens Ltd (2009). A £1.5M award from the MRC/EPSRC/ BBSRC Next Generation Optical Microscopy Initiative (2013-2020) subsequently facilitated the creation of the Mesolab, with further support provided by National Centre for the Replacement Refinement and Reduction of Animals in Research (NC3Rs) and the Leverhulme Trust. Highlighting the importance of funding opportunities across UKRI Councils, to facilitate the development of a technology.

The confocal microscope has become the gold standard in biomedical imaging, providing detailed images from within thick specimens. However, hundreds of these images must be stitched together to build an understanding of even a small object, such as a mouse embryo. With its 6mm field of view, the Mesolens enables researchers to study cells in situ, removing the need for extensive dissection and keeping a broader context to the areas being studied.

The Mesolab makes this unique technology accessible to researchers. The Mesolab is already opening up new areas of research and helping to position the UK as international leaders in this emerging area of optical imaging. The outputs from collaboration raise the profile of the UK's strength in high-end optics and electronics through this globally unique facility.



A whole adult female Drosophila imaged with the Mesolens. The colours correspond to depths in the fly, with near sections shown in yellow and the far images in purple or dark grey.

New software helps researchers analyse biomolecules

The open-source tool LcmsWorld, led by Professor Andrew Jones at the University of Liverpool, can assist researchers in high-performance visualisation and quality control analysis for liquid chromatography-mass spectrometry (LC-MS) data.

LC-MS is widely used in life science research to measure a large array of biomolecules, such as proteins and metabolites. Research using LC-MS generates a massive amount of complex data, which requires flexible tools for analysis. LcmsWorld, as a commercial grade and user-friendly software, aims to overcome the current lack of applicable visualisation tools and assist researchers in LC-MS data analysis.

The research group has been working on proteomics software and data standards, supported by several BBSRC-funded projects since 2009, including two from the bioinformatics and biological resources fund and one Tools and Resources Development Fund (TRDF) project. These grants have led to several open source, and freely available software pipelines, one commercialised package (Proteolabels), and widely used data standards in the proteomics fields. The team recognised that there was a lack of available tools for high-performance 3D visualisation of LC-MS data, and successfully applied for a combined Pathfinder + Standard Follow-on-Fund (FOF) project to create a new package known as LcmsWorld.

LcmsWorld is released currently as an open-source software tool, but the team are searching for licensing opportunities to take the software forward as part of a bigger commercial solution. This will allow for the tool to be sustained long term and further developed, and ultimately benefit research that employs LC-MS to better understand cell, tissue, and organ function, as well as disease processes.

Peer review

The wider peer review process has been highlighted as one of the areas where changes would bring clear benefits for technology development. Areas that could be considered include, but are not limited to:

- integrating and ensuring the clear recognition of all the outcomes and outputs of research (in line with the Declaration on Research Assessment (DORA))
- actively promoting the engagement of research technology professionals with the peer review and funding processes in their own right (see also Box 2 ALERT)
- supporting a broad spectrum of training activities (see skills and training section)

BBSRC has a key role in ensuring its peer review system is responsive to the identified needs. It is important that both assessment criteria and peer review guidance recognise that technology development is an integral part of contemporary bioscience and a key outcome of research. BBSRC should ensure that reviewers and panel members have appropriate technical expertise alongside relevant knowledge of the bioscience area under investigation, which would involve the inclusion of research technology professionals in the process. This should be regularly reviewed as the field further develops. BBSRC should also work with the other UKRI councils to ensure that the interdisciplinary nature of technology development is well supported.

As part of peer review, fostering an increased risk appetite was seen as a key enabler for technology development. BBSRC needs to find the right balance between investing in specific and late-stage funding of proven technology development against the ambitious early stage. This could be enabled through several mechanisms that include:

- greater emphasis on potential impact/promise rather than track record
- enabling more flexibility in the funding and peer review process in earlier stages of technology development, as this can be an enabler to more diversity in the variety of technology being developed
- formatting the application differently at different stages of technology development to reflect variation in risk appetite across the stages of technology development

Recommendation 2: BBSRC should consider innovation in its peer review processes and fully embed technology development as a recognised and valuable component

Box 2: Mid-range equipment funding

The ALERT funding opportunity is £13 million annually to support the purchase of mid-range equipment to be deployed collaboratively on a multi-project and multi-use basis within the BBSRC remit. BBSRC can provide up to 100% of the capital investment for the equipment itself, requiring all arrangements for ongoing staff support, management of and access to the equipment, as well as staff development considerations to be made by the submitting organisation. These arrangements are an essential part of the assessment. Including research technology professionals as applicants as well as panel members for ALERT has clear advantages for all parties because they bring key technical expertise and experience to the delivery and the assessment.

In recent years, BBSRC has increasingly sought to include facility managers in the ALERT assessment process and, for 2021 ALERT, BBSRC explicitly welcomed applications from eligible facility staff as either principal investigators or co-investigators. While eligible technical staff were already able to apply beforehand, applications from technical staff were low, potentially due to a lack of awareness amongst other reasons. BBSRC will work with partners to ensure eligibility is clear at all steps.

Skills and training

The review has highlighted several gaps in skills critical to technology development (Figure 4), with coding, programming and software engineering skills identified as the main area of need ahead of more specialised subject specific and technical expertise, and broader interdisciplinary and transferable skills. Other skills gaps of note include mathematical, physics and electronics skills, train the trainer schemes, and entrepreneurial skills.

For **coding, programming and software engineering skills** one of the key issues is based on the breadth of the area and the resulting difficulty in properly assessing a person's skills and associated training needs. The issue is compounded by a lack of standardisation in existing training courses. Moreover, the field of software development is particularly competitive, adding recruitment and retention problems.

Ideally, training in this area should target both users and developers, instilling a clear understanding of both the scientific and technical context. It must also clearly distinguish the roles of innovators and discovery scientists and their differing but important skillsets. A variety of mechanisms that reflect the range of skills required for technology development could help address the diversity of training requirements in this field. This could include centralised provision of standardised, modular and tailored training that is widely accessible in person and online to all career paths and stages.

The main challenge around **interdisciplinary skills** is the need to be competent enough in a range of disciplines to enable effective working across boundaries. This includes the need to understand and translate between disciplines while also understanding the broader context. A general lack of true interdisciplinary training opportunities has been highlighted by the community, affecting all career paths and career stages.

Options for skills-focused approaches adaptable towards technology development needs include, but are not limited to:

- train-the-trainer schemes
- dedicated support for interdisciplinary training
- support for vulnerable skills
- career development fellowships enabling 'field hopping'
- innovator focused programmes
- technology development apprenticeships
- mentoring and shadowing
- community-driven networks to facilitate cross-disciplinary engagement and minimise expertise siloing

These could be enabled through training opportunities that build upon people-focused schemes such as doctoral training, BBSRC Strategic Training Awards for Research Skills (STARS), the Innovation Scholars scheme supporting secondments and innovative training to upskill researchers, and the Flexible Talent Mobility Account (FTMA) scheme supporting exchanges of researchers and technicians in both directions between academia and industry.

While recognition of the inherent cross-cutting nature of technology development and role of BBSRC as part of the wider UKRI and UK funding ecosystem will be important, agreeing a clear definition of what 'interdisciplinarity' means in the context of technology development will be crucial. This definition, as well as what a clear route towards developing relevant skills could look like, and what roles existing training schemes can play, needs to be unpacked with the community.

Subject specific and technical skills by their nature vary broadly across the biosciences, but some common themes include lack of clear career paths and recognition for technical experts and their talent, and lack of available training particularly in instrument development related skills, seen as particularly relevant for technology development. In addition, specialist technical skills need specific training initiatives to ensure that these vulnerable skills are not lost.

A need for **entrepreneurial and innovator skills** was highlighted by a subset of the technology development community. It will be important to recognise the specific skill sets required for activities towards translation and commercialisation as they are distinct from the other more research-focused training needs.

Recommendation 3: BBSRC should prioritise short and long-term actions to support different training needs and career stages, with an emphasis on interdisciplinary and innovator skill sets

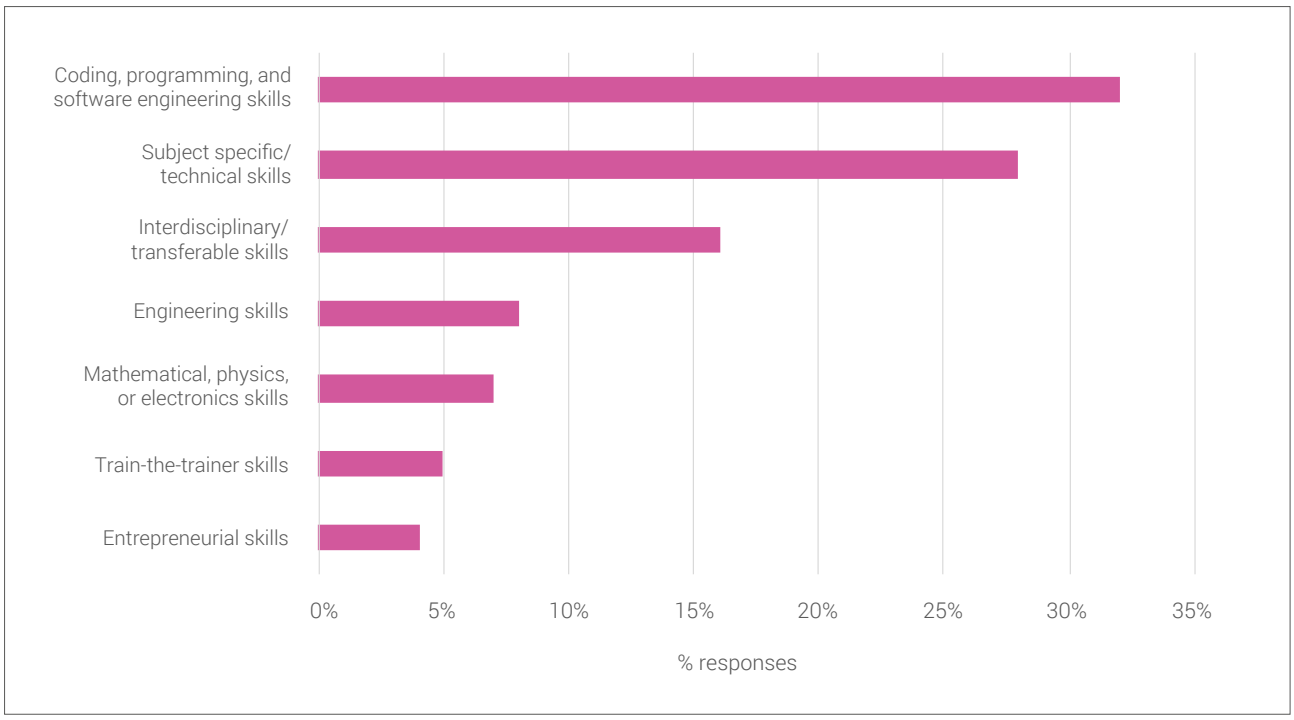


Figure 4: Key skills gaps for technology development in the biosciences as identified by the community

Box 3: Training the next generation

Training is underpinning for the future of technology development, and therefore the biosciences more generally. Exciting schemes exist in this space, including both fellowships and apprenticeships (see Royal Society of Biology).

- Science Industry Partnership Life Sciences 2030 Skills Strategy highlights the development of and facilitates the uptake of apprenticeships as skills priorities for the life sciences.
- The Broad Institute Summer Research and Summer Scholars programmes promotes ways to engage students in science and encourages diversity.
- Arkwright Engineering Scholarship is the most esteemed scholarship of its type in the UK, designed to inspire students to pursue their dreams and change the world as a future leader in engineering.
- The Advanced Therapies Apprenticeship Community (ATAC) offers an experience-driven degree programme uniquely designed to help employers who are leading bioscience, data science and statistical initiatives to satisfy their talent needs.
- EMBL's ARISE programme gives fellowships for technology developers and engineers to advance technology and methods development in the life sciences and learn how to lead service--providing research infrastructures.
- Training from the Hartree Centre (STFC) is application focused, designed to enable individuals and businesses to take full advantage of digital technologies.

Research technology professionals

Technology development in the biosciences requires a diversity of talent and skill sets that enable breakthrough ideas, and their refinement and commercialisation. Research technicians and technology and skills specialists (research technology professionals) cover this diverse range of roles that are fundamental and key to the future of technology development and the biosciences. Their talent for innovation, expert knowledge and technical competence is central to the field. Research technology professionals are co-creators in technology development, and they must be empowered and recognised at all stages and by all stakeholders.

The review highlighted that support for research technology professionals engaged in technology development is currently underdeveloped. Clear recognition of the vital role research technology professionals play in the research and innovation landscape in the UK is needed in the biosciences and beyond. The career pathway of research technology professionals needs to be clear and distinct from the academic career pathway, and not limited by the constraints applied to a technician role. The provision of tailored and continued training and upskilling opportunities, and sustainable career development have all been identified as areas that would benefit from intervention and feed into the professionalisation of this vital community.

UKRI is a signatory of the Technician Commitment, intended to champion technical careers in research and innovation. In its action plan, UKRI lays out how, as a funder, employer and policy organisation, it will work towards ensuring visibility, recognition, career development and sustainability for technicians working in research and innovation organisations, across all disciplines and sectors within our remit in both the near and longer term. Research technology professionals focused on technology development for the biosciences should be in a position to benefit alongside all other technician communities from the activities UKRI and BBSRC undertake as part of their commitment.

The review highlighted that the diverse range of individuals working within technology development are not necessarily aware of UKRI's support or their eligibility for funding that enables their recognition as co-creators in technology development. Community-focused communication and guidance could be beneficial to increase awareness. One first step could be increased visibility for the actions UKRI and BBSRC are already undertaking in this space, like the UKRI Resume for Research and Innovation (see Box 4 R4RI) and eligibility for BBSRC funding that includes BBSRC Discovery Fellowships being broadened to include applicants not holding a PhD. The BBSRC mid-range equipment funding opportunity ALERT provides an example where technical staff are already actively engaged as applicants and assessors (see Box 2 ALERT). BBSRC needs to continue working with all stakeholders to ensure eligibility is clear at all stages of the application process for research technology professionals.

Recommendation 4: BBSRC should work with the research technical professional community to highlight their talent and promote their central role in technology development in the biosciences

Research technology professionals as an integral part of the funding process

Professor Pippa Hawes is the Head of Bioimaging at the Pirbright Institute with the joint responsibilities as a technician and as a group lead. Professor Hawes served as Chair of BBSRC's mid-range equipment call, ALERT, in 2021 and is aware of the value research technology professionals bring to the peer review process. Professor Hawes felt research technology professionals could be advantageous as peer reviewer "Research technology professionals tend to take an altruistic science angle, without personal research biases, assessing only on merit", whilst also bringing a "technical sense-check" as to whether the proposed instrument(s) were able to examine the posed research question.

Through engaging in the peer review process, Professor Hawes was able to "observe and learn how interactions in peer assessment take place" whilst "learning where in the field technology is developing". Professor Hawes found the process "really enjoyable, learning about facilities and individuals, chatting to people with a wide variety of backgrounds". Professor Hawes stated that in order for peer review processes to evolve to be more inclusive of research technology professionals, "visible representation of research technology professionals on panels is really important", and that when a research technology professional is approached for a panel "the particular skills that they bring [to the peer review process] needs to be mentioned".

Recognition of technology development

Culture change

A recurring theme of the review is that technology development as an activity needs to be regarded as more 'prestigious'. As part of this there is a need to keep moving the bioscience community culture forward, so that the recognition and value of non-hypothesis driven activities, such as technology development are fully understood and embedded, and that an open approach to technology, hardware and software development is always taken.

The perception that technology development is not judged on its own merits is reflected more broadly in the underlying issues that led to the creation of the Declaration on Research Assessment (DORA), recognising the need to improve the ways in which the outputs of scholarly research are evaluated. As a signatory to DORA, BBSRC is committed to promoting best practice so that the value of all research outputs are equally acknowledged. BBSRC should ensure that all activities undertaken in view of the declaration include clear recognition for outcomes emerging from technology development research and innovation.

There is also a need to recognise the importance of team science, as only with a strong base for team science will technology development thrive. Teams need to recognise the range of people and talent that are needed, and that diversity is part and parcel of the technology development process. BBSRC should demonstrate long-term commitment towards technology development as an inclusive and diverse research environment. People and ideas should thrive and be supported and encouraged. Everyone must be enabled to participate in, contribute to, and benefit from BBSRC and UKRI investments in research and innovation.

There is clear recognition in the research and innovation community that research culture is an extremely important but complex topic to address. The Royal Society's 'Changing Expectations' programme, Wellcome's report on research culture and UKRI's own activities supporting a healthy research and innovation culture (see also Box 4 R4RI) are only a few of many examples highlighting the breadth of the topic. Some research culture concerns highlighted by the technology development community will already be recognised in ongoing work, but BBSRC needs to make sure that the technology development aspects are well integrated into the broader activities in this field. BBSRC should also understand the diversity of people and talent involved in the whole end-to-end process of technology development in the biosciences, to ensure an evidence-based approach to the delivery of culture change.

Recommendation 5: BBSRC should promote the value of diversity and team working in the biosciences and foster an open, dynamic, and inclusive system of technology development in the UK

Terminology

Technology development by design and across its life cycle encompasses a broad and diverse range of activities and talent in the research and innovation community. Different communities using their own respective languages, including evolving and/or sector-specific definitions of technology development as a term, mean that at this point there is no agreed common language among technology developers for the biosciences.

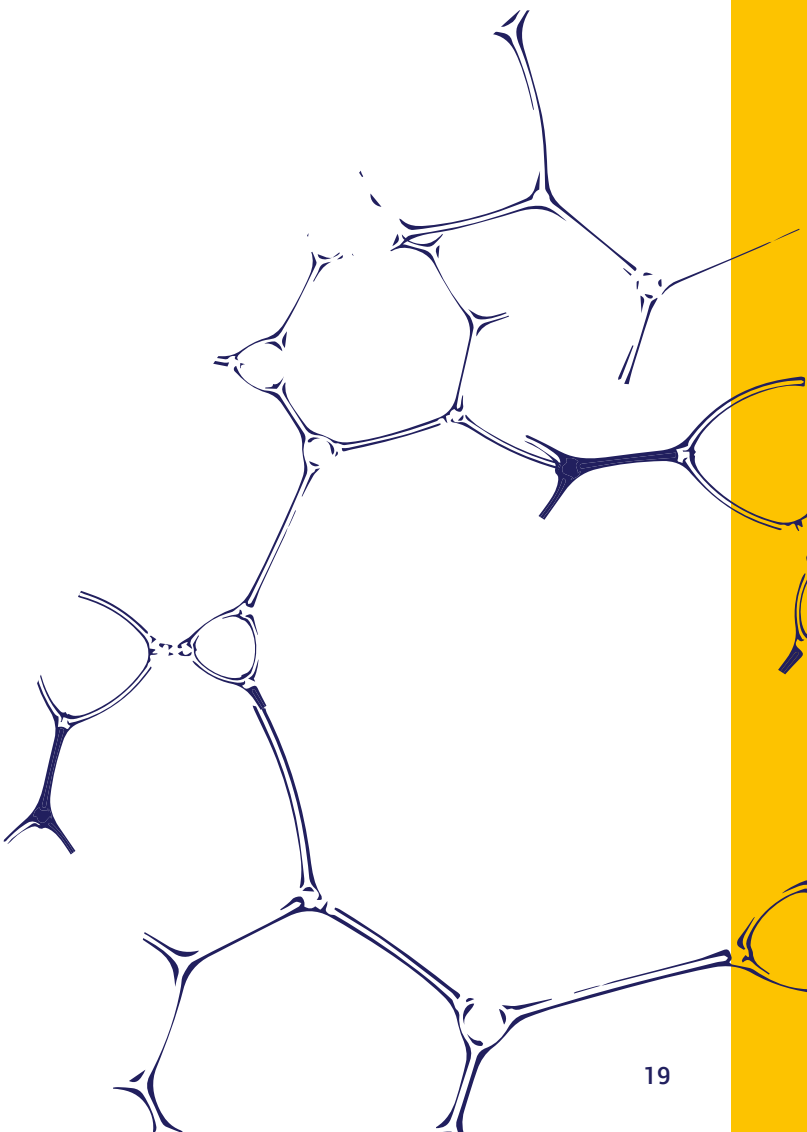
While the technology readiness level (TRL) scale can in principle be used to describe the stages of maturity for evolving technology, by itself it does not represent a sufficiently robust measure to structure discussions about technology development in the biosciences. The community highlighted in particular that technology development is not as linear or measured as the TRL scale might imply. Technology can move in both directions during an iterative development process, and the time needed to pass a particular TRL stage is not the same for each technology.

With the inherent cross-cutting and interdisciplinary nature of technology development in mind, this disconnect between communities currently represents a barrier for wider engagement. Community-led activities to counteract this could focus on building connectivity, discussing commonalities and differences in terminology, and increasing coordination and knowledge exchange.

Recommendation 6: BBSRC should consider mechanisms to bring together the technology development communities and facilitate interdisciplinary engagement

Box 4: Changing culture - UKRI Résumé for Research and Innovation (R4RI)

UKRI will be adopting the Resume for Research and Innovation (R4RI) in all funding opportunities that require a track record section. This narrative CV format is an evolved version of the Royal Society's Résumé for Researchers (R4R). Designed together with the research and innovation community, R4RI aims to broaden what is visible and valued in assessment. The format gives applicants an opportunity to capture the much wider range of contributions, skills and experiences compared to traditional academic CVs, and to provide context around the impact of their contribution. In this way, R4RI also better recognises the value of varied career paths and career types. UKRI is also working with other organisations to explore the use of R4R-like narrative CVs in funding and non-funding (promotion, recruitment and more) uses.



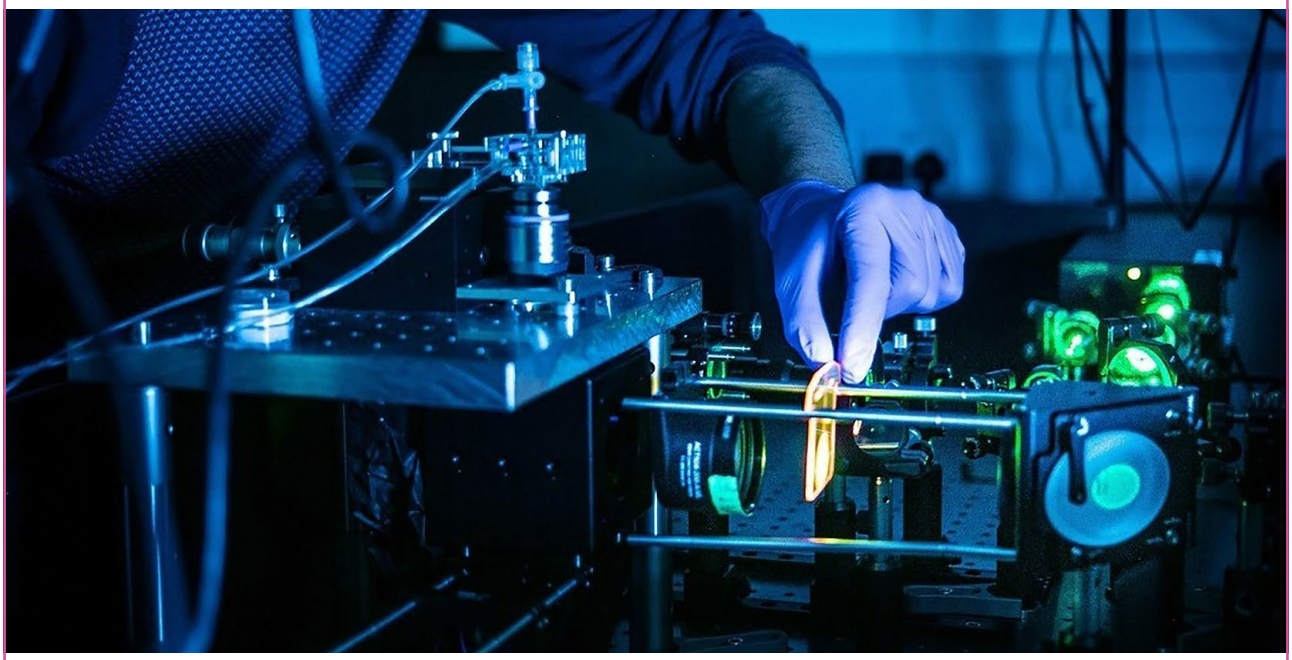
Team science: collaboration aims to combine 3 new technologies

A collaboration between the University of Oxford, University of Liverpool, and the Wellcome Sanger Institute, led by Professor Justin Benesch, led to the prospect of a revolutionary single-cell proteomics platform. The BBSRC contributed approximately £5.5 million to this vision via a Strategic Longer and Larger (sLoLa) grant.

The platform aims to combine 3 new technologies, including nanopore technology for inferring the amino acid sequence of proteins, escape-time electrometry to measure their charge, and mass photometry to measure their mass. The project will focus on detecting and elucidating the effect of post-translational modifications, as this is at the core of a large degree of complexity in proteome research. Progress in proteomics has been limited due to the existence of millions of human proteoforms, yet a relative inability to characterise them with existing, costly technologies.

This sLoLa project clearly demonstrates the value of a team science approach. Various fields, including technology development, MS-based proteomics, post-translational modifications, bioinformatics and microbiology, are working collaboratively towards the resolution of a major challenge in proteomics-based research. Collaboration of technology developers with life scientists during this project plays a crucial part in focusing the technology's impact on where it is most useful and relevant.

The project aims to provide the platform technology needed to transform proteomics research, enabling researchers to quantify proteins and detect their post-translational modifications. Filling this critical knowledge gap could lead to economic and social benefits, such as better understanding of disease and drug resistance.



This collaboration is developing a new proteomics platform that leverages single-molecule sensing.

Support landscape

Infrastructure

The concept of a support landscape includes a range of activities already highlighted in the report, but also requires digital and physical infrastructures that underpin the diverse and complex field of developing transformative technology.

The review consistently highlights the critical link between the ability to effectively sustain technology development and the presence of a supporting infrastructure. Challenges highlighted by the community focus on accessibility of existing and state-of-the-art novel technologies, with notable gaps most commonly encountered at the initial development stage.

A holistic approach towards support with clear guidance on how to effectively navigate such a complex landscape could open up significant opportunities to move the area of technology development forward and advance the frontiers of discovery in both exciting and novel directions.

Targeted community engagement will be essential to develop a clearer understanding of the specific infrastructure needs for technology development, and to determine the most effective and sustainable approach for sector-specific support.

Software

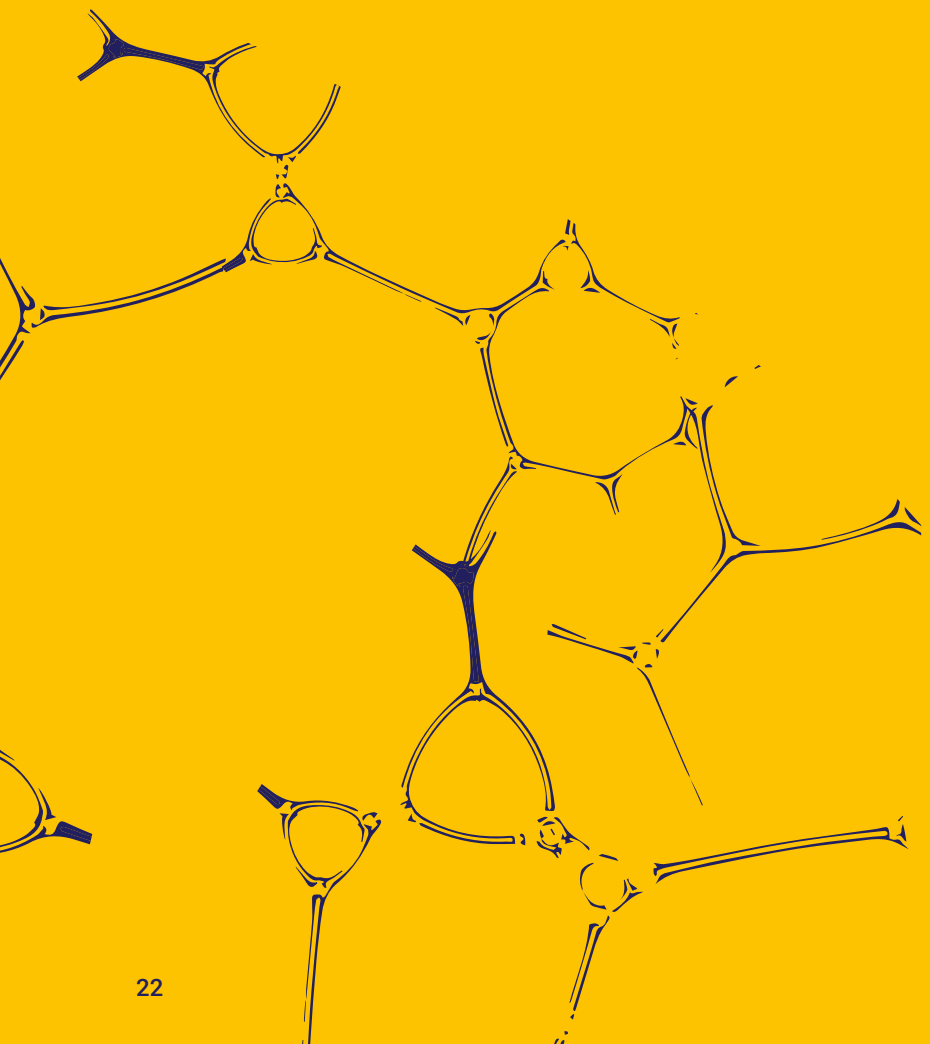
The review also identified a key need for software maintenance in technology development, supporting adaptive maintenance to ensure things work with new technologies or perfective maintenance to make the technology more robust or usable. The review recommends that BBSRC should prioritise making things adaptive and robust to ensure long-term functionality, over reactive maintenance. More broadly, this identified need reflects the current and future importance of all aspects and types of data in technology development and the biosciences as highlighted earlier in the review.

Activities in support of the development and maintenance of software should be undertaken with the wider recommendations of this review in mind. The need for both infrastructure access and software maintenance support have also been highlighted in the UKRI Infrastructure Roadmap Programme and BBSRC Review of Data-Intensive Bioscience, respectively, as areas critical for enabling bioscience research and innovation.

Recommendation 7: BBSRC should consider opportunities to support the underpinning infrastructure required for technology development

Next steps

The Review of Technology Development has identified a range of substantial challenges for BBSRC to respond to and the need to ensure that BBSRC is involved in innovative, exciting, and emerging technology areas, not just across its portfolio but also across UKRI. The immediate next step will be to develop an implementation plan to allow for a comprehensive and robust range of responses to each of the individual recommendations. Different approaches are available to implement each of the recommendations, some of these options will be operational while others will be policy changes. However, it is clear that for some recommendations further investment will be needed. Therefore, the evidence gathered as part of this review will feed into BBSRC's longer term strategy and will help to form part of a case for increased investment in the biosciences more broadly.



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