Centres for Doctoral Training 2018: Priority Area Descriptions

Foreword

EPSRC are pleased to publish the 30 priority areas for the 2018 Centres for Doctoral Training call for proposals. These have been developed through engagement with our research and user communities and our partners in the UKRI family, building on the research and training strategies developed through the most recent Balancing Capability exercise completed in early 2017. Our formal advisory groups have played an important role in their development: starting with our individual Strategic Advisory Teams [https://www.epsrc.ac.uk/about/governance/sats/] providing input into EPSRC Themes on initial topics and interdisciplinary links; followed by our cross-EPSRC Strategic Advisory Network [https://www.epsrc.ac.uk/about/governance/san/] taking a holistic view of the set of priority areas; and finally formal sign-off by EPSRC Council [https://www.epsrc.ac.uk/about/governance/council/] in December 2017.

The basis for each priority area is a clearly identified need for cohesive cohort based, doctoral-level training in engineering, physical sciences and related disciplines in the UK. Within each priority area description we have articulated the outcomes we expect to achieve by investing in Centres for Doctoral Training, a description of the scientific scope of the area and some key features we expect for CDTs in the area.

The scope of the areas vary, with some more focused areas where we expect to support a smaller number of Centres as well as some more broad-ranging areas where we expect to make a number of complementary investments. In the latter case, we would not expect a single Centre to cover the full remit of the priority area and we have highlighted our expectations in this regard in each priority area description.

We look forward with interest to receiving high-quality, innovative proposals through both the priority areas stream and the open stream, and to investing in a suite of Centres for Doctoral Training which will train future leaders in science, engineering and innovation and drive UK prosperity.

Dr Amanda Chmura
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1. Design and Innovation in Inclusive Technologies for Health and Care

Investing in CDTs in this area will produce highly skilled researchers focused on devices and technologies that maintain health, treat illnesses and maintain people's independence. Training will address the gap between, on the one hand, the science & engineering expertise and strong design skills that underpin technological development and, on the other, expert understanding of clinical needs and how innovative devices and technologies could help to tackle these.

This area offers huge potential in a range of fields, including: robotics; prosthetics & orthotics; rehabilitation, pre-habilitation & assisted living; surgery (including minimally invasive surgery); digital methods/devices for monitoring, measuring & diagnostics; and device-enabled drug delivery. But there are challenges too, in fields such as: biological compatibility; human-centred systems; hardware; longevity; power/energy management; robustness; wearability & portability; remote & real-time monitoring; data capture; and acceptability to users. This is the context within which CDTs must deliver a sound understanding of device and technology design, development, evaluation and manufacture, by providing an excellent foundation in state-of-the-art principles and methods in the field of innovation for healthcare. Note that this area only includes sensing & imaging as part of integrated patient-centred therapeutic platforms.

CDTs in this area:

- Should deliver training that covers: design principles & creativity; science & engineering skills for medical technologies; methods for developing devices, products or technologies; design process techniques, methods & tools (including sustainable design); human- & user-centred design principles; factors affecting device/technology deployment; assessment of effectiveness, reliability & efficiency; and data acquisition & analysis.
- Should address innovation management, risk analysis, ethical principles (especially relating to healthcare technology research), data protection, privacy, and security.
- Should ensure students understand (i) how their research relates to real-world problems and (ii) routes to translation and impact (including in emerging global markets).
- Should be highly interdisciplinary and provide a paradigm of collaborative approaches to addressing challenges (e.g. by offering experience at the clinical translational interface).
- Should provide students with training and experience related to issues identified in the Healthcare Technologies Impact and Translation Toolkit [https://www.epsrc.ac.uk/research/ourportfolio/themes/healthcaretechnologies/strategy/toolkit/].
- Should provide understanding of global health research and healthcare delivery where health conditions and economic/social constraints are very different from those in the western world.

Applications are not expected to cover the full breadth of this priority as described. EPSRC expects to make a small number of investments in this area, subject to quality.

2. Design and Manufacture of Complex Soft Material Products

Investing in CDTs in this area will produce highly skilled people who can contribute strongly to tackling challenges in the design and manufacture of products made from complex soft materials (e.g., complex fluids, gels, foams, emulsions, colloids, particulates, as well as combinations such as particle-laden fluids). By developing an appreciation of the technical challenges presented across fundamental and applied approaches, individuals will be equipped with a powerful understanding of problems common to a variety of industrial sectors and of how to address them.

UK industry manufactures an extensive range of products from complex soft materials, including fast-moving consumer goods, food, paints, pharmaceuticals and chemicals. Approaches from chemistry, physics, engineering, and manufacturing disciplines can be harnessed for the design and manufacture of these materials. For example, through fundamental understanding of soft-matter structure, self-assembly, kinetics and properties, chemical and process engineering, or innovative manufacturing technologies. Note that CDTs addressing healthcare applications must focus on manufacture of small-molecule medicines; advanced therapies are covered by the 'Engineering for the Bioeconomy' priority area.

CDTs in this area:

- Should focus on an interdisciplinary approach to soft material products, training students to work together across relevant disciplines (e.g. physics, chemistry, chemical engineering, mechanical engineering, materials science, manufacturing) to reduce barriers to working across and between interfaces.
- Should engage strongly with industrial stakeholders to give students a robust appreciation of challenges (e.g. process safety, scale-up and intensification) shared by a range of sectors. It is expected that there will be collaboration with appropriate end-users in the design and delivery of training.
- Should provide wider skills training; enabling students to develop understanding of topics such as the pathway to scale-up/industrialisation, as well as considering responsible research and innovation, entrepreneurship, and the openness to change necessary to prepare them to work in a changing academic and industrial landscape.

Applications are not expected to cover the full breadth of all relevant physical sciences, engineering and manufacturing disciplines described. EPSRC expects to make a small number of investments in this area, subject to quality.

3. Digital Creative and Interaction Technology

Investing in CDTs in this area will further strengthen the UK's position as a world-leader in the digital creative economy. Training in the development and application of state-of-the-art digital technologies for human creativity and interaction will deliver skilled people whose impact will be felt where digital technology and computer science intersect with people-centred applications in areas such as the arts, entertainment, heritage, communication, and new media.

New technology redefines how humans interact with each other and with their environments, underpinning culture, society and the economy. This area therefore addresses the complex new challenges and opportunities presented by emerging digital technology (e.g. data science, artificial intelligence, immersive & sensory technology, or the Internet of Things) with regard to human creativity/interaction. The focus is on transformative design, development and application of technology that enhances or creates new user experiences, creative practices, media, forms of engagement, and means of expression, while aiding social and cultural inclusion, engagement, cohesion, and wellbeing. A key goal for this area of research and the economy is greater integration (e.g. project co-design) between technology providers and the industries deploying these technologies. The CDT training model is ideally suited to promoting such integration and to catalysing this highly interdisciplinary area of research.

CDTs in this area:

- Should deliver an interdisciplinary training programme that embeds a culture of co-creation and where digital technology interfaces with existing, new and emerging creative practices; the programme should also encompass human/social considerations and foster students' ability to solve problems and work collaboratively.
- Should provide specialised skills training relevant to the CDT's target areas/industries/markets.
- Should ensure direct engagement, partnership and collaboration with industry, technology users and wider stakeholders.
- Should be able to deliver agile, responsive innovation aligned with industry's needs.
- Should embed Responsible Research and Innovation [https://www.epsrc.ac.uk/research/framework/] in its processes, considering possible aspects such as ethics, privacy, security, and legislation with respect to working with human participants and with content or intellectual property generated by existing/new media.

Applications are not expected to cover the full breadth of this priority as described. EPSRC expects to make a small number of investments in this area, subject to quality.

4. Enabling Intelligence

Investing in CDTs in this area will equip the UK with highly skilled people across the full spectrum of artificial intelligence (AI) technologies, to the benefit of society and the economy. This training will strengthen the UK in three key interacting areas of AI: fundamental research (e.g. decision-making, machine learning, interactive AI); cross-disciplinary approaches to technology development (e.g. embedding safety and security, cultural/societal/ethical considerations, natural language processing, machine vision); and technology applications (e.g. developing novel tools that enable non-specialists to use AI technologies to aid decision-making).

AI technologies offer huge potential to turn vast data streams into knowledge, understanding and physical action, and to revolutionise productivity. As well as delivering innovations such as driverless cars, they are increasingly being used to improve manufacturing productivity in sectors as diverse as aerospace, automotive, food and pharmaceuticals. Areas of application also include healthcare, high-value data-driven service sectors such as insurance and advertising, and the automation of scientific discovery. Driving forward fundamental research, exploring real-use cases and tackling key issues such as bias, safety, security, trust, inclusivity, privacy, and transparency will release the potential and build societal confidence in AI. This demands a cross-disciplinary whole-systems approach spanning engineering and physical sciences, life sciences, economics, law, ethics and other areas.

CDTs in this area:

- Must specifically address and action Responsible Research and Innovation [https://www.epsrc.ac.uk/research/framework/] in the context of this area as part of the research and training agenda. Including aspects such as, the need for safety and security in the field of intelligent software and systems development, and the need for ethics in design and knowledge of the regulatory environment.
- Should deliver multidisciplinary taught programmes that reach beyond core computer science and include consideration of the wide-ranging applicability of intelligent technologies.
- Should encourage students to engage with industry and with users of AI technologies. This will help students to build up a picture of how research in this area can have an impact beyond the academic community, and then to integrate this understanding into their own research.

Applications are not expected to cover the full breadth of this priority as described. EPSRC expects to make multiple complementary investments in this area, subject to quality.

5. Energy Resilience through Security, Integration, Demand Management and Decarbonisation

Investing in CDTs in this area will help to achieve the Government's carbon reduction targets for the year 2050. Meeting these targets will depend on the availability of skilled people equipped to undertake a wide range of work on energy resilience, addressing the key issues of security, integration, demand management and decarbonisation of the whole energy system. Students will be trained to undertake whole-systems research which is inherently multidisciplinary – spanning engineering, physical sciences, computer science, mathematical sciences, and social sciences – and which demands the ability to communicate and work both with industry and with policy-makers.

Over the next 20-30 years, the UK's energy system will undergo rapid change – a task presenting a range of difficult technical, socio-economic, policy, and other challenges. Tackling these successfully will require expertise in fields including: secure, resilient energy infrastructure (e.g. networks); systems integration of new energy technologies (e.g. renewable supply, grid storage); understanding & reducing energy demand; and decarbonisation technologies, particularly for heating and cooling (e.g. waste heat utilisation, carbon capture & storage).

CDTs in this area:

- Must train students in a cross-disciplinary environment and should recruit students from a wide variety of backgrounds.
- Should ensure a whole-systems approach that helps to break down sector-specific or application-specific silos.
- Should involve a wide range of industrial partners and policy-makers, working on co-created problems.
- Should ensure appropriate end-user engagement in the design and delivery of training – for example, policy-maker engagement to demonstrate how research is taken into consideration in the development of government policy.
- Should work closely with existing structures/programmes (e.g. the Supergen programme [http://www.rcuk.ac.uk/research/xrcprogrammes/energy/EnergyResearch/SUPERGEN/], the UK Energy Research Centre [http://www.ukerc.ac.uk/] and End Use Energy Demand Investments) and align to challenges emerging from these.

Applications are not expected to cover the full breadth of this priority as described. EPSRC expects to make a small number of investments in this area, subject to quality.

6. Energy Storage and Conversion

Investing in CDTs in this area will ensure a population and a pipeline of world-leading specialists who make the UK the 'go-to' place to meet global industry's needs in energy storage and conversion. Through cross-disciplinary training that spans materials, manufacturing, physics, chemistry, engineering, ICT, and maths, the goal is to deliver a step change in innovation by producing people with a depth of specialist expertise and a breadth of understanding covering the whole energy system and the challenges involved in integrating storage and conversion technologies into it.

Energy storage and conversion (i.e. its utilisation following storage) permits the decoupling of generation from demand, allowing energy to be used at different times and in different places. Particularly in the context of the Government's carbon reduction targets for 2050, these technologies are a vital component of the wider energy system and are regarded as a promising growth sector for the UK economy. As well as embracing multiple underlying disciplines, training in this area could include fields such as power electronics and economics, and address the social, environmental, and political aspects of energy storage and conversion research.

CDTs in this area:

- Should ensure a cross-disciplinary, whole-systems approach that helps to break down sector-specific or application-specific silos
- Should strengthen links to research advances in materials engineering (for thermal storage) and manufacturing technologies (for scale-up and production), and build on established links to materials for energy applications, electrochemical services and power electronics.
- Should support a portfolio of training including electrochemical, hydrogen, kinetic and thermal storage, and underlying disciplines (engineering, physics, chemistry, maths, data science etc.).
- Should include a significant amount of industrial involvement, where appropriate. They should support ambitious, dynamic training environments that meets industrial needs and facilitate interaction with industry, with links established to other CDTs and large investments.

Applications submitted against this priority should look to cover the breadth of the area described. Applications are particularly welcomed that stretch beyond a primarily electrochemical focus. EPSRC expects to make a small number of investments in this area, subject to quality.

7. Engineering for the Bioeconomy

Investing in CDTs in this area will produce a generation of experts with wide-ranging, high-value skills that can address key challenges in the growing biotechnology sector and so further boost the UK's bioeconomy. Bringing a unique cross-disciplinary perspective to the interface between engineering and the biological sciences, they will be equipped to work across different levels in the sector, from developing processes and technologies, to translating these to commercially viable scale and integrating them into manufacturing environments.

Applying concepts from other disciplines to complex, versatile biological systems can offer valuable benefits. In particular, tools, principles, and new approaches drawn from engineering and the physical sciences have major potential to support the manufacture of end-products and intermediaries incorporating biologically based materials (including waste streams). They span both the design/development of novel biologically based resources, and the redesign of existing natural biological resources. Combining physical, chemical, and biotechnological processes, is especially relevant to, for example: the industrial chemicals sector; high-value products; advanced therapies (e.g. cell and gene therapies, tissue engineering); and development and exploitation of biological resources such as biologics, enzymes, and vaccines, through engineering.

CDTs in this area:

- Should deliver training developed in collaboration with, and relevant to, an array of industries: e.g. the pharmaceutical, regenerative medicine/healthcare, chemical, energy, food, personal care, water, and process sectors. (It is not necessary for individual CDTs to target every sector.)
- Should ensure they facilitate the level of interdisciplinary training necessary to enable students' combination of engineering, biological science, and other skills, to be applied across the rapidly changing biotechnology sector to exploit the emerging opportunities.
- Should address key challenges associated with bioprocessing, biotechnological processes and their use in the manufacture of products, and the provision of services.
- Should embed awareness of, and creative approaches to, formulation, metrology, scale-up, process development, and efficiency at an industrial scale.
- Should ensure appropriate understanding of Responsible Research and Innovation [https://www.epsrc.ac.uk/research/framework/, data issues, economics, regulatory issues and user-engagement strategies (e.g. at the clinical translational interface).

Applications are not expected to cover the full breadth of this priority as described. CDTs could take a broad view across the biotechnology sector or focus on a particular aspect of the field. EPSRC expects to make a small number of investments in this area, subject to quality.

8. Establishing Trust, Identity, Privacy and Security for a Hyper-connected Digital World

Investing in CDTs in this area will produce a generation of experts who can deliver a step change in tackling issues of trust, identity, privacy, and security (TIPS) in the field of digital systems and their interaction with the physical world. These experts will understand how to work with complex, pervasive, highly connected systems across a variety of sectors. They will also be able to relate to the needs of the people who use them; ensuring such systems are safe, secure, reliable, trustworthy, legally compliant, and ethically sound. As a result, security and trust will be inherent in digital systems that work easily, efficiently and effectively, and society will be better prepared and better able to deal with critical challenges.

In a world increasingly reliant on digital technology – including cyber-physical and autonomous systems, legacy systems and emerging 'disruptors' such as quantum technologies – there is a pressing need for TIPS-related advances. Specific research challenges for CDTs working in this field include: genuine anonymisation of data while still allowing computational analysis; building secure, resilient digital systems 'by design'; and enabling ordinary citizens to have confidence that systems are secure and work properly 'by default'. Other priorities include exploiting opportunities and mitigating risks posed by quantum technologies, and implementing ground-breaking techniques (e.g. automated testing) at scale in everyday digital systems.

CDTs in this area:

- Must deliver comprehensive training in Responsible Research and Innovation [https://www.epsrc.ac.uk/research/framework/]. In addition to a general appreciation for RRI this must include specific considerations and approaches in the context of this area. For example, training people how to build secure systems inevitably involves providing them with insights into how to break them. Students should therefore be equipped with the ability to reflect on their own and others' research behaviour, to recognise when something irresponsible or dishonest is being done, and to take appropriate action.
- Should employ an interdisciplinary, holistic approach to training that embraces both software and hardware technical challenges, alongside the economic, cultural, social, legal, ethical, design, behavioural, political, regulatory, and governance dimensions.
- Should ensure students can make a real difference to society – for example, by addressing the realities of human behaviour in a security/privacy context.
- Should work in close, ongoing collaboration with user stakeholders including industry, government, communities, and relevant agencies.

Applications are not expected to cover the full breadth of this priority as described. EPSRC expects to make multiple complementary investments in this area, subject to quality.

9. Fluids and Structures

Investing in CDTs in this area will ensure the UK has a supply of experts who have a deep understanding of challenges in fluids and structures, and who are highly skilled at translating fundamental knowledge into effective solutions across multiple sectors. Harnessing wide-ranging expertise, this new generation of specialists will have the ability to adopt and apply a systems approach that successfully integrates theoretical, computational and experimental methods to maximise the impact of their work.

Expertise in fluids and structures, and the interaction between them, plays a key role in tackling challenges across many sectors, especially the aerospace, automotive and process industries, as well as healthcare, energy generation and energy harvesting. The area encompasses all aspects of fluid dynamics including aerodynamics, hydrodynamics and topics relevant to process engineering (e.g. multiphase flows, rheology). Also included is the understanding of the performance of mechanical structures (including relevant acoustics and engineering dynamics). Key interdisciplinary challenges include non-destructive testing and dynamic fluid-structure interactions (e.g. how the dynamics of a flow is coupled to the dynamics of a structure; understanding the transition to turbulence).

CDTs in this area:

- Must deliver a solid, broad foundation of relevant underpinning skills that can be applied across a breadth of application areas.
- Must deliver training in a breadth of expertise, such as an understanding of applied mathematics and skills in modelling, simulation and experimental validation. Moreover, challenges in fluids and structures often need to be tackled using a systems approach, while also demanding an understanding of the challenges associated with working across different scales.
- Should equip students with an understanding of theoretical, computational and experimental methods, as well as relevant skills in applied mathematics. Students should have the ability to apply a systems approach that brings together all these aspects to address challenges relating to fluids and structures.
- Should recruit students from a variety of technical backgrounds (e.g. applied mathematics, aeronautical engineering, chemical engineering, mechanical engineering).
- Should develop genuine, strong engagement with problem-solvers and, in order to encourage cross-sector learning, establish links to a diverse range of industrial sectors.
- Should provide knowledge of and experience in how to position research to take the next steps towards translation and impact.

Applications are not expected to cover the full breadth of this priority as described. EPSRC expects to make a small number of investments in this area, subject to quality.

10. From Molecule to Product: Chemistry for Future Applications

Investing in CDTs in this area will meet the growing demand from across the UK's chemical-related sectors for highly skilled people with the expertise to accelerate the impact of UK innovations. Making a key contribution to challenges across the full chemicals continuum from discovery to end-product realisation, these individuals will combine a depth of chemical knowledge with an appreciation of the cross-scale issues that need to be addressed within the continuum.

A wide variety of companies in the chemicals manufacturing, pharmaceutical, personal care, healthcare, petrochemical, and energy sectors require highly skilled individuals able to design, synthesise and control the functionality of molecules and molecular products. Training should foster broad understanding of cross-scale challenges in chemical and related industrial processes, while focusing on specific parts of the chemicals continuum such as new synthetic methods, catalysis, chemical & process engineering, scale-up, integration of automation, process safety, or localised continuous manufacturing.

CDTs in this area:

- Should train students to work together across the disciplines of chemistry, chemical engineering and manufacturing to strengthen the chemicals continuum and address the increasing need to work at the interfaces between these disciplines.
- Should offer training that equips students with a breadth of scientific skills (potentially including modelling & predictive science) and an understanding of the importance of considering Responsible Research and Innovation [https://www.epsrc.ac.uk/research/framework/] including sustainability in chemical and process design.
- Should engage strongly with a range of industrial and other stakeholders in the evolving UK chemical industry and other sectors, including the growing number of start-ups and SMEs.
- Should ensure the students' industrial engagement experience enables them to develop a holistic understanding of cross-scale chemical innovation and the needs of a variety of potential end-users.
- Should provide wider skills training enabling students to develop the industrial awareness, entrepreneurship, flexibility and openness to change necessary to prepare them to work in the changing landscape of the UK chemical industry.

Applications are not expected to cover the full breadth of this priority as described, but all CDTs should address the wider issues relating to industrial translation. EPSRC expects to make multiple complementary investments in this area, subject to quality.

11. Future Computing Systems

Investing in CDTs in this area will underpin the UK's position at the vanguard of the next computing revolution. By producing a new generation of computer scientists, engineers and researchers with cutting-edge expertise in systems radically different from those of previous generations, it will create leaders in a growth area of the economy that will profoundly shape lives, businesses and public services in the years to come.

Demand is growing for computing systems that combine better connectivity and performance with security, reliability, affordability, and low power requirements. To meet this major challenge, next-generation systems could incorporate radically new architectures and exploit disruptive technologies such as quantum computing, photonic interconnects, and 2D materials. Developing truly optimised systems will also critically depend on the effective integration of everything from the design of novel electronics and hardware to software engineering. As computing becomes ever more complex, distributed, embedded, pervasive, and heterogeneous, academia and industry will have a vital, growing need for experts who not only understand whole-system and cross-layer challenges in an area both fundamental and broad, but can also communicate effectively with researchers in adjacent fields.

CDTs in this area:

- Must deliver exceptional training in computer systems and related areas, working across a range of disciplines to explore specific strategic aspects of the challenge presented by next-generation computing.
- Must produce students equipped to become members of a growing network of experts and technology leaders who understand whole computer systems, as well as working fluently across the boundaries with adjacent fields.
- Should provide students with a fundamental understanding of key issues such as security, reliability, energy consumption and software (including research software engineering and programming languages).
- Should enable students to understand the different computing-related needs and challenges facing different sectors.
- Should ensure students receive entrepreneurial training and enable them to benefit from the CDT's strong engagement with industry (e.g. via internships).

Applications are not expected to cover the full breadth of this priority as described. EPSRC expects to make a small number of investments in this area, subject to quality.

12. Future Connected Technologies

Investing in CDTs in this area will equip the UK with skills in the development and deployment of networked and interconnected systems that deliver maximum economic and societal benefit in areas such as smart urban environments and industry 4.0. In a field where research is expected to grow almost exponentially and demand in industry and academia for well-trained people will be huge, there is a need to nurture expertise in, for example, next-generation communications systems, distributed and pervasive sensor networks, and new forms of remote human interaction (e.g. connected virtual reality and haptic systems).

Connected and networked technologies present a range of hardware and software challenges: radio and control engineering, maths for signal processing and information systems, and cyber security, for instance. Training that equips students to tackle these challenges should be complemented by research into human interaction with pervasive systems and the uses of such systems. The aim is to produce experts with multidisciplinary skills who not only drive advances in underpinning technologies but also carry out domain-specific research in sectors such as transport, agricultural technology, healthcare technology, digital manufacturing, and the creative industries.

CDTs in this area:

- Must be both highly multidisciplinary and highly applied in nature. Both cross-disciplinarity and co-creation should be embedded in the student experience, with technology development a key focus.
- Should take an approach extending from research exploring technology fundamentals to the development and deployment of systems; such systems could have numerous applications.
- Should include research and training focused on technologies' resilience and security.
- Should incorporate Responsible Research and Innovation [https://www.epsrc.ac.uk/research/framework/] into the research agenda with training and research approaches including, for example, considerations of privacy, trust and other issues relating to the human dimension of pervasive technology.
- Should encourage interaction with industry, government and/or the third sector to allow students to build up a picture of the impact and implications of their research, and of how it will benefit community and society. To help maximise the impact of future research, students should also be given experience in addressing policy/regulatory issues.

Applications are not expected to cover the full breadth of this priority as described. CDTs may either be broad or focus on one specific field of technology or application. EPSRC expects to make a small number of investments in this area, subject to quality.

13. ICT Device Technologies

Investing in CDTs in this area will ensure the UK is supplied with highly skilled people who have a deep understanding of contemporary challenges in device technology. Their broad knowledge will enable them to adopt 'system' approaches – aiding integration of relevant technologies – and their appreciation of the breadth of devices' application in modern society will support translation and deployment of safe, secure ICT and robust systems.

The focus is on novel devices for storing, processing, and communicating information, as well as on devices to underpin future power electronic, radio frequency, terahertz, and photonic technologies. CDTs should produce research-trained people who will ultimately be able to drive advances in intelligent technology in areas such as healthcare and industry 4.0, and to address challenges including device manufacturability and machine-machine communication between trillions of devices. This will potentially lead to solutions to important societal challenges in fields such as cyber-security and energy supply.

CDTs in this area:

- Must offer cohorts a broad range of training in device technology. Skills should cover aspects of hardware research, from device physics to computer architectures.
- Should equip students to devise 'system' approaches to ICT device technology research, enabling integration across all aspects of hardware research. This could include training in fields of engineering, microelectronic design and quantum technology.
- Should drive a culture change towards Responsible Research and Innovation [https://www.epsrc.ac.uk/research/framework/], for example ensuring students not only consider how people will interact with technology but also develop devices compatible with, or enabling, safe and secure ICT systems.
- Are encouraged to ensure collaboration with engineering disciplines, e.g. quantum computing, healthcare technology, energy, manufacturing and instrumentation.
- Are encouraged to ensure collaboration with disciplines in the physical sciences, particularly materials science, to co-design or exploit novel materials.

Applications are not expected to cover the full breadth of this priority as described. EPSRC expects to make a small number of investments in this area, subject to quality.

14. Materials Engineering and Manufacture

Investing in CDTs in this area will ensure the UK remains at the forefront of research and innovation in materials engineering and manufacture, supporting high-profile UK manufacturing sectors and their supply chains. This will be achieved by developing the next generation of materials engineers, equipped with the high-value skills and underpinning expertise needed to address key processing and manufacturing challenges.

Materials underpin many research areas and application domains, playing a vital role in the aerospace, defence, automotive, construction, energy, healthcare and electronics sectors, as well as their supply chains. Spanning the processing of metals & alloys, composites, ceramics and polymers, as well as processing/scale-up of multi-material systems and functional or 'smart' materials, training will embed an understanding of process design, analysis, optimisation and control (including, as appropriate, modelling & simulation and non-destructive testing). Net shape or near-net shape manufacturing technologies (e.g. additive manufacturing, printing, precision manufacturing, laser processing, machining, curing, joining technologies and metrology) are also a potential CDT focus; other challenges that could be encompassed include the field of highly customised and/or localised manufacture.

Note that functional discovery and synthesis are covered by the 'Targeted Design and Discovery of Functional Materials' priority area; soft-matter science, complex fluids/flows, particulates and formulation by 'Design and Manufacture of Complex Soft Material Products'; tissue engineering/regenerative medicine and large biomolecules by 'Engineering for the Bioeconomy'.

CDTs in this area:

- Should deliver training in core competencies that combines appropriate experimental and theoretical techniques to develop an understanding of the benefits and limitations of both current capability and novel approaches. Although not expected to cover all material types or sectors, CDTs should provide a curriculum focused on transferrable skills.
- Should provide a multidisciplinary environment where students can acquire knowledge of techniques through access to appropriate equipment; training addressing resource efficiency, design for recyclability and consideration of end-of-life use may also be embedded in the programme.
- Should deliver user-relevant research projects providing knowledge and understanding of real industrial challenges/applications. Centres should incorporate substantive user engagement across more than one sector.
- Where the focus is on manufacturing (fostering skills related to the impact that changes to manufacturing processes have on product performance) CDTs are expected to be co-created with some of the key industrial stakeholders.
- Where the focus is on healthcare (e.g. biomaterials, implants, coatings) CDTs must provide multidisciplinary training; this should include experience of working at the clinical translational interface and develop students' understanding of ethics, health economics, data issues, care pathways, and of how to position research to take the next steps to translation and impact.

Applications are not expected to cover the full breadth of this priority as described. EPSRC expects to make multiple complementary investments in this area, subject to quality.

15. Mathematical and Computational Modelling

Investing in CDTs in this area will boost productivity in UK industry by tackling the shortage of skilled people with a comprehensive understanding of the fundamentals of mathematical and computational modelling. Training will produce experts who have the skills to use their knowledge to address complex, real-world problems, and who are equipped to work collaboratively across traditional disciplinary boundaries to solve both new and existing challenges in academia and industry. These experts will understand the steps towards impact and uptake of new modelling tools, and use this appreciation to inform the way they develop their research.

Modelling systems based on mathematical concepts and computational methods can produce valuable insights into challenging research questions that are too complex to explore using analytical methods and physical experiments. The focus of training needs to be on the theoretical underpinning of mathematical and computational modelling across the full range of scale and scope, the development of specialist state-of-the-art modelling expertise, and its application to a range of disciplines (such as maths, ICT, physical sciences and engineering) and sectors (such as healthcare). Achieving significant advances in this field will require close, iterative dialogue between mathematicians, theoretical scientists, experimentalists, and experts in application areas.

CDTs in this area:

- Should expose students to the breadth of modelling techniques and approaches in order to best inform future model development. This could include statistical models as well as hybrid models that mix data-driven and physics-driven input.
- Should offer a breadth of training across relevant disciplines and develop connections between them.
- Should link theory and methodology to real-world problems and real systems, wherever appropriate.
- Should pinpoint how students will develop an understanding of complex data relevant to the CDT’s focus, as well as an understanding of the constraints that apply to this data.
- Should encourage a collaborative approach to tackling modelling problems relevant to areas of application.
- Should highlight existing and planned links to problem-owners (in academia, business or the public sector) who need new, innovative modelling solutions.

Applications are not expected to cover the full breadth of this priority as described. EPSRC expects to make multiple complementary investments in this area, subject to quality.

16. Mathematical and Physical Sciences at the Life Sciences Interface

Investing in CDTs in this area will help address strong demand, in both industry and academia, for highly skilled people from the mathematical and physical sciences who have an understanding of the challenges at the interface with the health and life sciences. This training will equip students to work effectively across disciplinary boundaries both in academia and a range of sectors, including agricultural technology, medical technology and pharmaceuticals.

Quantitative, experimental and theoretical approaches originating in mathematical and physical sciences can be harnessed to tackle many problems in the health and life sciences – for example, the need to conduct investigations across a range of length scales or to synthesise biological and biologically active molecules and achieve a fundamental understanding of them. Potential also exists to develop innovative physical, chemical and mathematical tools/techniques specifically targeting health and life science challenges. As well as sharing training needs in terms of interdisciplinary understanding, such challenges have common industrial and scientific drivers.

CDTs in this area:

- Should bring together students from a range of mathematical and physical sciences disciplines (e.g. physics, chemistry, materials, mathematical sciences) and equip them with the skills needed to work at and across disciplinary interfaces and to collaborate effectively across the mathematical, physical, health and life sciences. The focus should be on effective collaboration between mathematical and/or physical sciences and the health and life sciences.
- Should have a strong focus on end-user engagement, to expose students to a variety of challenges in the health and life sciences. This should include working directly with problem-owners across academia and industry (e.g. biologists, researchers in the health sciences and those working in the pharmaceuticals, agricultural technology, and medical technology sectors).
- Should, through specific training (e.g. in mathematical and computational skills, ethics, and communication skills), address key requirements for transferrable skills needed by graduates working in the life sciences sector.

Applications are not expected to cover the full breadth of this priority as described. EPSRC expects to make a small number of investments in this area, subject to quality.

17. New Science and Technology for Sensing, Imaging and Analysis

Investing in CDTs in this area will increase the supply of highly trained people with the knowledge and multidisciplinary skills to develop novel sensing, imaging and analysis technologies and so help deliver major benefits for society and the economy. Their expertise will be geared, not only to accelerating advances in this key underpinning field of research, but also to meeting real-world needs – for example, through co-creation of effective new technology with end users.

Impacting on almost every aspect of life, sensing, imaging and analysis are vital underpinning capabilities for academia, industry and society. Training in fundamental skills will enable novel tools, techniques, instruments and devices to be developed for a number of applications, such as healthcare, space-monitoring, measurement and metrology. Key challenges to be tackled include, but are not restricted to, real-time monitoring in remote/extreme environments and increasing social connectivity and community to reduce loneliness.

Harnessing engineering, physics, chemistry and materials science, this is an inherently cross-disciplinary area that also draws on expertise from other disciplines including social, biological, and environmental sciences. It addresses issues such as systems integration, data capture & processing, power & energy management, robustness, and environmental impact.

Note that this area includes new approaches to health and care sensing and analysis technologies, but not diagnostic imaging or the incorporation of such technologies into an integrated patient-centred therapeutic platforms.

CDTs in this area:

- Should enable students to understand needs and challenges in different sectors/applications, and how state-of-the-art tools, techniques, instruments and devices will translate into these sectors/applications (including ethical, cultural, policy, standards and legislation issues).
- Should provide a solid, broad foundation of relevant underpinning skills that can be deployed across a wide range of application areas, and take a cross-disciplinary approach that helps to break down sector-specific or application-specific silos.
- Should take a multidisciplinary approach to training which includes engineering and physical sciences in concert with other disciplines where appropriate.
- Should engage strongly with problem-owners (e.g. at the clinical translational interface, for health and care applications), users of technology and, to encourage cross-sector learning, a diverse range of industries.
- Should provide knowledge of and experience in the positioning of research so it can take the next steps towards translation and impact.
- As part of their training in Responsible Research and Innovation [https://www.epsrc.ac.uk/research/framework/] students should develop understanding of ethics, regulation frameworks, and relevant social and cultural contexts.

Applications are not expected to cover the full breadth of this priority as described. EPSRC expects to make multiple complementary investments in this area, subject to quality.

18. Next-Generation Medical Imaging

Investing in CDTs in this area will boost the ongoing drive to achieve radical breakthroughs in medical imaging that enable better understanding of disease and more effective, patient-centred diagnosis. The UK is a global leader in medical imaging – attracting significant investment from large multinational companies – and continued skills development is vital if it is to retain this position in an era when challenges such as cost-efficiency, mobility, portability, and the personalisation of medicine are increasingly pivotal.

If medical imaging is to keep pace with aspirations (e.g. in precision medicine and the visualisation of human pathology), a step change is needed in the development and translation of cutting-edge imaging technology – for example, in areas such as instrumentation, molecular probes, multi-scale/ multi-modal imaging, detector & sensor technology, real-time imaging at point of care, and data capture, connectivity, extraction & presentation. It will also depend on collaborative approaches spanning the physical, clinical, and social sciences, as well as maths, and development of entrepreneurial skills that enable commercial exploitation of sustainable technology platforms.

CDTs in this area:

- Should provide an excellent foundation of understanding of the current state of the art in medical imaging across a range of modalities and their applications.
- Should engage strongly with relevant stakeholders.
- Should train students to develop approaches that address unmet clinical needs and/or offer major advantages over current technologies, with an identified place in the patient pathway.
- Should incorporate observational studies and implementation science, to determine how technologies must move forward with respect to patients and healthcare professionals.
- Should introduce students to the very different needs of healthcare settings in the developed and developing world, as well as to industry's needs and its approaches to innovation.
- Should provide students with training and experiences related to issues identified in the Healthcare Technologies Impact and Translation Toolkit [https://www.epsrc.ac.uk/research/ourportfolio/themes/healthcaretechnologies/strategy/toolkit/]. In particular, students should gain a good understanding of routes to translation and impact, and of economic constraints and drivers in emerging global markets.
- Should be highly interdisciplinary and provide a paradigm of collaborative approaches to addressing challenges (e.g. by offering experience at the clinical translational interface).

Applications are not expected to cover the full breadth of this priority as described. EPSRC expects to make a small number of investments in this area, subject to quality.

19. Nuclear Fission and Fusion for Energy

Investing in CDTs in this area will meet demand, in academia and the nuclear industry, for people with the skills needed to support the UK's current nuclear commitments, the Government's new nuclear-build programme, and the UK's commitment to international fusion R&D. By underpinning a key low-carbon power generation option, skills in the field of nuclear fission will help to meet the Government's carbon reduction targets for 2050 and support its clean growth and industrial strategies. High-level expertise in nuclear fusion will ensure the UK maintains an appropriate level of capability in a technology with remarkable longer-term potential.

Power-generation capacity based on fission currently produces around 21% of the UK's electricity and, as existing reactors retire from service, new-generation plants are expected to come online. Further into the future, fusion technology could generate an almost limitless supply of clean power. Ensuring nuclear energy delivers for the UK, in both the shorter and longer term, means enabling the highly interdisciplinary nuclear sector to meet a range of challenges in fields including materials research, extension of plant lifetimes, decommissioning, radioactive waste management, novel fuel cycles, robotics & engineering, and regulation & certification.

CDTs in this area:

- Must engage with the technical challenges associated with the nuclear new build programme
- Should aim to translate cutting-edge nuclear science into engineering solutions with real-world applicability.
- Should, where possible, accommodate the areas of overlap between fission and fusion (although it is recognised there are many areas where no such overlaps exist, e.g. plasma physics and transuranic chemistry), and recruit students from a wide variety of backgrounds.
- Should secure significant industry involvement.
- Should engage with non-industry stakeholders such as the National Nuclear Laboratory [http://www.nnl.co.uk/], the Nuclear Decommissioning Authority [https://www.gov.uk/government/organisations/nuclear-decommissioning-authority] and the Department for Business, Energy and Industrial Strategy [https://www.gov.uk/government/organisations/department-for-business-energy-and-industrial-strategy].
- Should seek to engage internationally, especially with the US, Japan, the Republic of Korea and India, as well as with France's Alternative Energies and Atomic Energy Commission [http://www.cea.fr/english/Pages/cea/the-cea-a-key-player-in-technological-research.aspx].
- Should provide access to, and training in the use of, a range of analytical equipment.

Applications are expected to cover most (though not necessarily all) of the aspects of the area as described. EPSRC expects to make a small number of investments in this area, subject to quality.

20. Physics for Future Technologies

Investing in CDTs in this area will produce cohorts of researchers trained across core fields of fundamental physics and ready to work in the UK's growing, strategically vital high-tech and knowledge-intensive industries. Students will be equipped with the skills and understanding to work across disciplinary boundaries and to contribute to the development of innovative applications of physics that drive important new breakthroughs.

A wide variety of physical phenomena – in fields such as condensed matter, quantum, atomic, molecular, and optical physics – have the potential to underpin future innovations across a broad range of technologies and applications. A CDT's focus could be on any aspect of these phenomena. The training delivered is expected to include both theoretical and experimental approaches and, where relevant, to link to wider research areas. Although this area is broad in scientific terms, its strategic focus is on producing physicists who not only have a strong appreciation of the potential applications of their research, but also develop skills that will enable them to progress in emerging sectors (e.g. quantum technologies) as well as a whole range of traditional industries (e.g. electronics, energy, manufacturing).

CDTs in this area:

- Must introduce students to an inter- or intra-disciplinary mind-set. Exposure to theoretical and experimental techniques beyond their own field of research will allow them to gain a broad understanding of the research landscape; it will also facilitate collaboration and knowledge transfer within and between different physics disciplines, and with related disciplines.
- Must deliver additional training that supports translation of science to industrial applications, as well as its wider dissemination, and prepares students for work in high-tech sectors. Embedded across all years, this training could focus on, for example, science communication, entrepreneurship, commercialisation and awareness of manufacturing processes.
- Must engage with relevant UK stakeholders and end-users of physics research. This will not only prepare students to work in the UK physics-based sector but also ingrain in them an appreciation of the translational pathway for innovative ideas that arise from their research.
- Should be able to define clearly: (i) their own position in the current skills landscape, in both UK and global terms; (ii) the long-term strategic need for end user aware cross-disciplinary training in the field of physics.

Applications are not expected to cover the full breadth of this priority as described. EPSRC expects to make a small number of investments in this area, subject to quality.

21. Power Electronics

Investing in CDTs in this area will meet the urgent need to increase the supply of highly skilled people with a deep understanding of contemporary challenges in power electronics. These experts will also have the breadth of knowledge to use their skills to develop whole-systems approaches that successfully meet these challenges, which include the need to develop power electronics that deliver increased efficiency, more compactness and greater robustness.

Power electronics deals with devices, circuits and systems that manage electrical energy. Cutting across a variety of sectors, this multidisciplinary area embraces, for example, electrical and mechanical engineering, computer science, physics, and maths. The relevant technology covers power levels from milliwatts to gigawatts. Tackling contemporary challenges in power electronics requires simultaneous, complementary progress at multiple scales, from devices to whole systems. As a result, expertise must be both deep and broad. While classical approaches to doctoral training can provide the necessary depth, a cohort-based approach is the most effective way of delivering the necessary contextual awareness.

CDTs in this area:

- Must work closely with major existing investments of relevance to this area such as the Centre for Power Electronics.
- Should provide broad, multidisciplinary training that includes skills in, for example, engineering, computer science, physics and maths, and should set this in the context of key application areas (e.g. energy networks, electrified transport and low-power electronic devices).
- Should set out a clear strategy for training individual cohorts around a key challenge or a set of complementary challenges.
- Should have strong partnerships with a range of industrial organisations and ensure each student has the opportunity to work closely with industrial partners.
- Should encourage a collaborative, whole-systems approach to addressing key challenges in power electronics.

Applications are not expected to cover the full breadth of this priority as described. EPSRC expects to make a small number of investments in this area, subject to quality.

22. Pure Mathematics and its Interfaces

Investing in CDTs in this area will deliver a change of culture in pure mathematics, strengthening this discipline and maximising its impact both on other disciplines and across industry. With the equality and diversity agenda, intra-disciplinary co-operation, collaborative problem-solving and interaction with industry to the fore, broad-based training will enhance interactions between core theoretical areas of the mathematical sciences and mathematical aspects of other disciplines, producing students skilled in multiple fields of mathematics and equipped to work at their interfaces, as well as to combine techniques across disciplines and aid knowledge transfer.

Pure mathematics comprises six main areas: algebra, geometry & topology, number theory, probability, mathematical analysis and logic & combinatorics. These share primary links with one another and with areas such as complexity science, digital signal processing, mathematical biology, mathematical physics, non-linear systems, numerical analysis, statistics & applied probability, and theoretical computer science. Innovation in pure mathematics often requires tools and techniques from neighbouring fields of the mathematical sciences and/or related scientific disciplines, while broad dissemination of progress in pure mathematics often demands knowledge of the disciplines that will directly benefit. Ideally, CDTs in this area will forge links between multiple pure areas, plus academic and/or industrial links to areas that are immediate beneficiaries, with a view to facilitating knowledge dissemination and translation to applications.

CDTs in this area:

- Must develop strong links with disciplines and/or industries that will benefit from the skills they develop and the research they undertake. Industries are more likely to engage with pure mathematics when they have access to a multidisciplinary problem-solving group of the kind that CDTs are ideally suited to provide.
- Should offer a breadth of training across a mix of fields of mathematics and provide a compelling rationale explaining why they are focusing on these fields.
- Should provide a clear vision outlining how students will develop skills and experience in multiple fields and techniques.
- Should be able to define clearly: (i) their own position in the current skills landscape, in both UK and global terms; and (ii) the long-term strategic need for the training they aim to provide.

Applications are not expected to cover the full breadth of this priority as described. EPSRC expects to make a small number of investments in this area, subject to quality.

23. Quantum Technologies

Investing in CDTs in this area will produce a generation of experts ready and able to innovate and ensure the quantum technologies sector not only remains strongly rooted in the UK but also delivers long-term economic, social and other benefits. By combining an understanding of the needs of those who use quantum technologies with an ability to make these transformational technologies efficient, safe, secure, reliable, trustworthy, legally compliant and ethically sound, these experts will drive progress in a wide variety of sectors.

In the emerging area of quantum technologies, the second generation of products will exhibit astounding properties that profoundly affect our lives. With the potential to transform imaging, sensing, metrology, communications and computation, for example, these products will have a major impact on sectors such as finance, defence, aerospace, energy and transport. The ability to unlock the full potential of this technology-focused field will require a firm foundation in scientific strengths that the UK has already developed, for example in physics, photonics, electronics, algorithms, signal processing, computer science, materials, devices & systems, manufacturing and relevant application areas (e.g. communications, imaging and sensing).

CDTs in this area:

- Should deliver training that spans relevant disciplines, including those relating to application areas for quantum technologies.
- Should structure training consistent with the emerging nature of quantum technologies, so that both the training delivered and the skilled individuals produced not only meet the needs of the area as it develops but can support it in the longer term too.
- Where CDTs choose to address any of the following challenges, specific training needs have been identified for each:
    - Quantum communications – here, it would be critical for CDTs to consider integration with other new technologies as well as with legacy infrastructure, while simultaneously delivering security, safety and reliability.
    - Quantum computing and simulations – here, CDTs should mirror and match the evolution of this field in the UK, including new aspects as it develops.
    - Quantum sensing, imaging and metrology – here, CDTs should develop systems engineering & integration to ensure appropriateness to end-applications.

Applications are not expected to cover the full breadth of this priority as described. EPSRC expects to make a small number of investments in this area, subject to quality.

24. Renewable Energy

Investing in CDTs in this area will drive development of renewables technologies by training highly skilled people who combine multidisciplinary expertise, deep knowledge of specific challenges and broad understanding of the whole energy system within which renewables are deployed. This will enable current/future renewables-related challenges to be tackled and help deliver the low-carbon generating capacity vital to achieving the Government's carbon reduction targets for 2050, especially in the context of the need for further cost reductions, efficiency improvements and long-term policy incentives in the sphere of renewable energy.

Generation of energy from clean, inexhaustible sources is growing at unprecedented rates but maintaining momentum requires fresh insights and new breakthroughs. The focus is on delivering training in leading-edge research addressing user-inspired challenges in offshore wind, wave and tidal, solar, geothermal energy*, and bioenergy. Relevant topics include offshore/marine structures, safety & resilience, installation, operation & maintenance, decommissioning, grid integration, synergies with the oil & gas industry, geotechnics, thin films & new materials, direct solar energy conversion, biomass combustion, biomass to liquid biofuels, gasification and co-firing. CDTs could address one or more of these by developing and applying expertise in – and promoting collaboration and knowledge-sharing between – an array of fields such as data analytics, modelling & simulation, power networks, materials research, structural integrity & materials behaviour, systems integration, robotics, autonomous & intelligent systems, social-technical issues and environmental sciences.

CDTs in this area:

- Should not just support training across a breadth of application areas but also address a broader set of challenges, including end-user engagement, policy uncertainty and confidence in returns on investment.
- Need to continue to inform policy and the public in order to help bring forward large installations and secure recognition of renewables as major contributors to the energy system.
- Should take a cross-disciplinary, whole-systems approach to help break down sector-specific or application-specific silos.
- Should develop links with a diverse range of industrial sectors in order to encourage cross-sector learning.

Applications are not expected to cover the full breadth of this priority as described. EPSRC expects to make multiple complementary investments in this area, subject to quality. The Natural Environment Research Council (NERC) are pleased to confirm co-investment of up to £2.2M towards this priority in support of Centres working across the EPSRC/NERC interface.

*Geothermal energy, whilst not in EPSRC remit, is an area of interest for NERC. It should not be the sole focus of a Centre. NERC intends to co-fund this priority areas in the broadest sense, not solely this area.

25. Resilient Infrastructure

Investing in CDTs in this area will meet the need for a new generation of people with the necessary multidisciplinary skills and expertise to understand, maintain, protect, and improve the infrastructure critical to the UK's prosperity. They will ensure national infrastructure can remain resilient to technological, demographic, economic, social and environmental change, and will enable the UK to stay at the vanguard of research and innovation in this vital field.

Infrastructure comprises many components, including the built environment, flood and coastal erosion management, water treatment and distribution, transport, and waste management – with crucial interdependencies between these systems. (Note: digital communications and energy fall mainly within other priority areas.) Achieving resilience requires an approach which incorporates not only civil engineering but also mechanical engineering (e.g. focusing on the performance and inspection of structures), chemical engineering, mathematical sciences, and manufacturing, for example, and which enables infrastructure-based industries to learn from each other. Especially in light of increasing demand on infrastructure, long-term interdisciplinary solutions rooted in theoretical and experimental work are needed in fields such as asset maintenance (e.g. mitigating damage, corrosion and/or fatigue), protection against shocks (demand-related, economic or environmental), and understanding of how infrastructure can respond to changes in population, the built environment and climate (e.g. via decarbonisation).

CDTs in this area:

- Must provide a multidisciplinary research environment for training students recruited from different disciplines.
- Are expected to train students (i) across traditional boundaries in both theoretical and experimental work, and (ii) in the interrelationships and interdependencies between different types of infrastructure systems.
- Should consider the role of both emerging and existing technologies, as well as the opportunities for increased use of ICT.
- Should be industrially-relevant and ensure they meet both academic and industry training needs. They should therefore deliver training in 'soft' skills (e.g. project management) alongside training in core disciplines such as fundamental engineering and mathematics.
- Should train students in the wider economic, policy and social implications of research on infrastructure, which is a field where the Government has a strong interest. This will equip students to engage successfully with policy-makers and other stakeholders.

Applications are not expected to cover the full breadth of this priority as described. EPSRC expects to make multiple complementary investments in this area, subject to quality.

26. Robotics and Autonomous Systems

Investing in CDTs in this area will generate cohorts of highly talented, highly skilled people with the broad foundational and cross-disciplinary expertise to tackle real-world challenges in the fast-growing field of robotics and autonomous systems (RAS). This will enable the UK not only to develop and maximise its strengths in RAS but also to seize the many opportunities that are already emerging such as in creating new capabilities in challenging and extreme environments; enabling healthy/independent living; ensuring safe, efficient transport; and developing next-generation manufacturing technologies– and will continue to emerge – in this increasingly crucial area.

RAS involves technologies that seek to develop robotic tools capable of performing useful tasks in the real world. This requires flexible, self-functioning systems equipped with varying levels of decision-making autonomy. Relevant topics include, for example, soft robotics, bioinformed / bioinspired / biomimetic systems, human-robot interaction, collaborative robotics, systems security, and sensor integration. Underpinning research needs to embrace disciplines such as control engineering, artificial intelligence, verification & validation, computer vision, and platform integration (e.g. mechatronics, materials development, software and electronic engineering), and to draw on the expertise of other disciplines where appropriate. Embedding safety, security, ethics, legal considerations, and end-user engagement in the design process is a critical component of research activities in this field.

CDTs in this area:

- Must be capable of upskilling and reskilling the highest-calibre students, recruited from a range of backgrounds in terms of disciplines and demographics.
- Must embed Responsible Research and Innovation [https://www.epsrc.ac.uk/research/framework/] within the research and training agenda.
- Should complement a university or universities' existing research strengths in RAS.
- Should provide a strong foundation that enables students to adapt within the field as well as to develop and implement a systems approach in the deployment of RAS.
- Should address real-world challenges by providing training in collaboration with end-users of RAS technologies.
- Should promote and encourage cross-disciplinary and co-creation approaches to working.

Applications are not expected to cover the full breadth of this priority as described. EPSRC expects to make multiple complementary investments in this area, subject to quality.

27. Statistics for the 21st Century

Investing in CDTs in this area will meet rising demand for expert statisticians across science, business, government and healthcare, for example, where their skills will be key to enabling the next generation of life-changing, prosperity-building breakthroughs in research and innovation. As the world becomes ever more data-rich, training in statistics is increasingly vital to driving forward disciplines ranging from engineering and economics to medicine and machine learning. Cutting-edge skills in the development of new techniques in statistical theory and methodology are also crucial to delivering solutions to an array of real-world industrial and societal problems.

Statistics is a diverse discipline that includes, but also extends far beyond, data analytics. Maximising its value to society and economy will require highly skilled experts who can not only develop new statistical methods but also use their expertise to apply these to a breadth of areas. It will demand the ability to work collaboratively and to communicate and work with researchers from other disciplines as well as industry and policy/decision-makers. CDTs are especially well-suited to meeting these needs – for instance, by forging links with a variety of industrial partners and exposing students to a wide range of real-world challenges. In particular, CDTs can meet industry's urgent need for statisticians combining technical excellence with the communication, team-working and other skills essential to applying this excellence in a business context. Although CDTs' main focus should be on the development of novel statistical theory and techniques, there should be links to the applications which inspire advances in the field.

CDTs in this area:

- Should offer a breadth of training in novel statistical theory and methodology
- Should link theoretical advances to areas of application.
- Should include external partners interested in applications of statistics and applied probability.
- Should, where appropriate, develop connections with relevant research across the RCUK portfolio.
- Should recognise: (i) that the areas of application for statistics are broader than data science; and (ii) the potential to recruit graduates from computer science, theoretical physics and other numerate disciplines beyond the mathematical sciences.
- As part of their training, students should develop an understanding of a number of other subjects such as regulatory affairs and economics, and be encouraged to develop transferrable skills.

Applications are not expected to cover the full breadth of this priority as described. EPSRC expects to make a small number of investments in this area, subject to quality.

28. Sustainable Processes and Products

Investing in CDTs in this area will create a generation of technical experts capable of catalysing a transition to a more sustainable UK economy, ensuring long-term productivity and resilience. These highly skilled people will have the ability to transfer sustainable practices into industry, and meet growing demand from a range of UK sectors for expertise in embedding sustainability into industry and driving competitive business performance.

This area spans all aspects of the development, scale-up and assessment of sustainable processes and products (including chemistry, physics, materials science, process engineering, bioprocess engineering, and operational research). The key focus is on providing a breadth of skills covering sustainability and its application across different sectors, as well as fostering a full understanding of issues such as resource efficiency, the circular economy and how sustainable options impact other aspects of processes, industries, the environment and society. The scientific focus of a CDT might include: process/product design, material synthesis and scale-up, light-weighting & material substitution, waste reduction & utilisation, remanufacturing, energy/ water-efficient processes and development of new techniques to assess sustainability.

CDTs in this area:

- Should provide a solid foundation of skills that can be used to develop new sustainable processes and products and drive innovation forward.
- Should combine specific technical expertise with awareness of sustainability challenges across all disciplines, with students trained to work together across physical sciences, engineering, manufacturing and analytical disciplines to understand how to embed sustainable practices. It may also be appropriate to consider the boundaries with the biological and environmental sciences.
- Should train students to take a whole-systems approach, building understanding of the impact of choices made over product lifetimes (including end of life) and apply this understanding to their research. Techniques may include (new approaches to) life-cycle analysis and sustainable development indicators.
- Should enable students to develop a comprehensive understanding of the potential trade-offs between sustainability and other considerations, and to be able to encourage development of sustainable practices within industries.
- Should have a strong industry focus and provide interaction with a broad range of end-users and policy-makers, including those involved in regulation and standards. This will provide students with an appreciation of the challenges involved in embedding sustainable practices.

Applications are not expected to cover the full breadth of this priority as described. EPSRC expects to make a small number of investments in this area, subject to quality.

29. Targeted Design and Discovery of Functional Materials

Investing in CDTs in this area will deliver a critical mass of graduates with the cross-disciplinary skills and industrial knowledge necessary to design and discover novel functional materials and realise their translation across a range of sectors. With the aim of underpinning the transformation of the UK's materials sector, this will include developing the ability to tackle functional materials challenges posed by a wide variety of modern technologies and applications.

Functional materials have specific properties and functions, and make a strong contribution to UK economic competitiveness. They are important across a number of classes of material (e.g. semiconductors, electrical/electronic materials, 2D materials, magnetic materials, polymers, plasmonic materials, metamaterials, and biomaterials). CDTs need to train students in modelling, design and characterisation of novel functional materials with a diverse range of applications ranging from electronics and sensing to enabling room-temperature quantum computing.

CDTs in this area:

- Should provide students with exposure to, and training in, a wide range of design, modelling and characterisation techniques drawn from multiple disciplines appropriate to the focus of the CDT. This will ensure they develop the mind-set and skills to bridge traditional disciplinary boundaries. Development of novel materials increasingly integrates theory and simulation with experimental discovery and characterisation, and an understanding of processing routes, intellectual property and device design.
- Should develop training programmes to equip graduates with the awareness and tools to bridge the gap between academic materials research and industrial materials deployment – for example, focusing on translation, innovation and entrepreneurship, or on industrial scale-up, testing, or the sustainability of materials.
- Should expose students both to a wide range of application areas and to the wider materials innovation and technology landscape, with strong industry involvement in both research and training.

Individual Centres are not expected to cover the full breadth of the applications, techniques and functional materials described above, although awareness of this range should feature in every CDT's ethos and training. EPSRC expects to make multiple complementary investments in this area, subject to quality.

30. Towards a Data-driven Future

Investing in CDTs in this area will meet the growing need across business and academia for talented people who, in an increasingly connected world characterised by large and complex datasets, are able to exploit the potential of data to generate insight and value. Training will focus on developing skills that span the breadth of data science – this could include machine learning, novel mathematics, statistics, data applications and draw on many other disciplines – in order to tackle today's often cross-cutting challenges in this area.

The rapidly expanding scale, complexity and diversity of data generated by digital technologies, sensors and the Internet of Things offer huge potential to deliver benefits for society and the economy. Applications of data science are becoming increasingly wide-ranging, in sectors such as the digital industries, healthcare, and manufacturing. To realise these possibilities, data science is necessarily a broad field that requires a corresponding breadth of training. Consideration and understanding of the social, legal and ethical aspects of data (e.g. issues such as data protection, privacy and ownership) are also ever more important.

CDTs in this area:

- Must embed Responsible Research and Innovation [https://www.epsrc.ac.uk/research/framework/] into the research and training agenda, especially with regard to data privacy and ownership.
- Should complement the broader landscape in data science, including national institutes.
- Should give students a broad appreciation of technical, social, legal and ethical aspects of data.
- Should engage with organisations facing real-world challenges resulting from the generation of large and/or complex datasets (e.g. decision making in an increasingly complex world), as well as with data-users and policy-makers more generally
- Could deliver training in the underpinning methods for data science, such as mathematical and statistical methods and machine learning. This could also include data management, data mining, database theory, and data visualisation.
- Could train students to harness novel mathematics and statistics for data analysis to produce easily understood decisions. They could involve the explainability of algorithmic decisions to maintain transparency, accountability and public confidence in machine learning and data science.

Applications are not expected to cover the full breadth of this priority as described. EPSRC expects to make multiple complementary investments in this area, subject to quality.