

Institution: Ulster University
Unit of Assessment: 11 Computer Science and Informatics
<p>1. Unit context and structure, research and impact strategy</p> <p>1.1 Unit context and structure</p> <p>Research in Computer Science and Informatics at Ulster, referred to as CS@Ulster/The Unit, has seen measurable expansion since REF2014 as a result of our research and impact strategy, achieving >75% increase (69.6 FTE) in the number of staff with significant responsibility for research(SRR), with >216% increase in the number of ECRs, >17% increase in the number of contracted researcher staff (CRS) totalling 248 person years, >45% increase in PhD researchers registered and >54% increase in grant expenditure. CS@Ulster research is conducted within two schools, the School of Computing, Engineering and Intelligent Systems (SCEIS, Magee Campus, Derry/Londonderry) and the School of Computing (SoC, Jordanstown Campus), both within the Faculty of Computing, Engineering and the Built Environment. The unit is directed by Prof Damien Coyle (Professor of Neurotechnology) and co-directed by Professor Luke Chen (Professor of Data Analytics) through three overarching research centres; the Intelligent Systems Research Centre (ISRC 30.9 fte), the Artificial Intelligence Research Centre (AIRC 17.2 fte) and the Pervasive Computing Research Centre (PCRC 21.5 fte). These centres operate cohesively and undertake fundamental and applied interdisciplinary research and translational research, organised in 11 interrelated research themes/teams (nine led by Professors) with a significant emphasis on R&D and impact in life and medical sciences:-</p> <p>The Intelligent Systems Research Centre <i>vision is to develop a bio-inspired computational basis for Artificial Intelligence.</i></p> <p>Teams:</p> <ul style="list-style-type: none"> • Computational Neuroscience and Neuromorphic Engineering (Lead: McDaid, Prof of Computational Neuroscience (5 fte): Modelling cellular and network level brain structure and function to develop understanding of neural systems and to create biologically inspired algorithms and hardware. • Cognitive Neuroscience and Neurotechnology (Prasad, Prof of Intelligent Systems, 3.2 fte): Intelligent signal/image analysis of electroencephalography; magnetoencephalography, functional near-infrared spectroscopy, functional magnetic resonance imagery and diffusion tensor imaging, to understand brain dynamics, structure and function and to develop ways to restore, maintain and enhance physical and cognitive function through brain-computer interfaces. • Cognitive Robotics (Coleman, Prof of Vision Systems, 7.5 fte): Bioinspired algorithms for sensory systems and robotic technologies with human-like sensing capabilities for seamless interaction, with applications in vision systems, assistive devices, tactile sensing, and industry 4.0. • Intelligent Data Analytics (Coyle, Prof of Neurotechnology, 10.2 fte): Bio-inspired paradigms for AI, machine learning and scalable computing for complex, challenging data analytics problems, many of which are industry-led. • Cyber Security and Web technologies (Curran, Prof of Cyber Security, 5 fte): Developing secure, intelligent web technologies that can deliver context aware knowledge and actions in real-time. <p>The Artificial Intelligence Research Centre <i>vision is to develop AI technologies that underpin an intelligent society, empower people and support a sustainable future.</i></p> <p>Teams:</p> <ul style="list-style-type: none"> • Learning, Modelling and Optimisation (Glass, Senior Lecturer, 5 fte): fundamental research in machine learning, mathematical modelling, (e.g., opinion dynamics, ecological networks, pandemic modelling), mathematical optimisation (Bayesian optimisation, multi-objective optimisation).

- **Knowledge, Reasoning and Decision-making (Liu, Reader, 4.2 fte):** fundamental research in knowledge representation, reasoning, logic (including theorem proving, formal verification) and decision making.
- **Informatics and Systems (Zheng, Professor of Computer Science, 8 fte):** research driven by specific real-world challenges in bio/geo-informatics, multimedia, swarm systems, digital interventions, food authentication, virus detection, text/video/image analytics.

The Pervasive Computing Research Centre *vision is to realise ubiquitous environmental monitoring and data analytics solutions with a focus on health and wellbeing.*

Teams:

- **Human Activity Recognition (Nugent, Prof of Biomedical Engineering, 7.5 fte):** research relating to sensor-based technologies with applications in activity recognition, behaviour monitoring, assistive technologies for healthcare and independent living.
- **Ubiquitous intelligence (Chen, Prof of Data Analytics, 7 fte):** research in IoT and edge computing, process analytics and automation, privacy and security, and user-centred intelligent cyber-physical systems.
- **Human-Computer Interaction (Cleland, Lecturer of Data Analytics, 7 fte):** through the centre's Living Lab focus, research on the human factors associated with interactive computing systems, multimodal interaction, and affective and wearable computing.

1.2 Research and Impact strategy

Our research themes focus on fundamental and applied research – our fundamental research enables and demands the development of new algorithms, many of which are inspired by gaining knowledge of natural and biological systems, particularly the brain. Dealing with challenging data (electrophysiological, biological, medical, and industrial data) at a fundamental level demands the development of expertise in AI, machine learning, data analytics and engineering capability therefore, these research topics transcend all our research themes and have enabled us to develop a strategy that involves:

1. crossing disciplinary boundaries
2. diversifying our funding sources
3. enabling our researchers to contribute to the increasing demand for expertise and capability in AI presented by industry with a major emphasis on life and medical sciences.

Our research strategy is developed as a team involving the individual centre directors, the unit research directors (RDs), the faculty associate dean for research and impact and our faculty executive dean (Maguire returned in CS@Ulster). The Faculty Leadership Team (FLT) meet weekly, the faculty research executive meet monthly and the two schools (SCEIS and SoC) both have School Research Executives that involve centre and team/theme leads and focus on research operations, strategy, initiatives, and support mechanisms. Strategic options are proposed and reviewed at all levels with yearly and five-year overarching research KPIs set by the University Senior Leadership Team (SLT) and FLT. Focus is placed on aspects of these targets each year with additional seed funding provided to stimulate, seed and drive new initiatives. Areas of potential for research excellence, recognition, growth and impact are identified by staff and/or teams and those of strategic importance for the unit are supported whilst alignment with existing priorities are considered.

1.2.1 Overarching objectives and strategy summary

The unit's strategy objectives and overarching strategy in this period, which were aligned with Ulster Strategic Plan and Research and Impact plan, were: -

- **to enhance research quality and awareness** - through active engagement with Ulster's research development programme (SOARING (see section 2.1.1)) and educating and training staff on the importance of research planning, statistical evaluation and undertaking

collaborative research (checklist in Fig. 1 highlights key aspects of our quality enhancement awareness strategy).

Check list for staff submitting papers

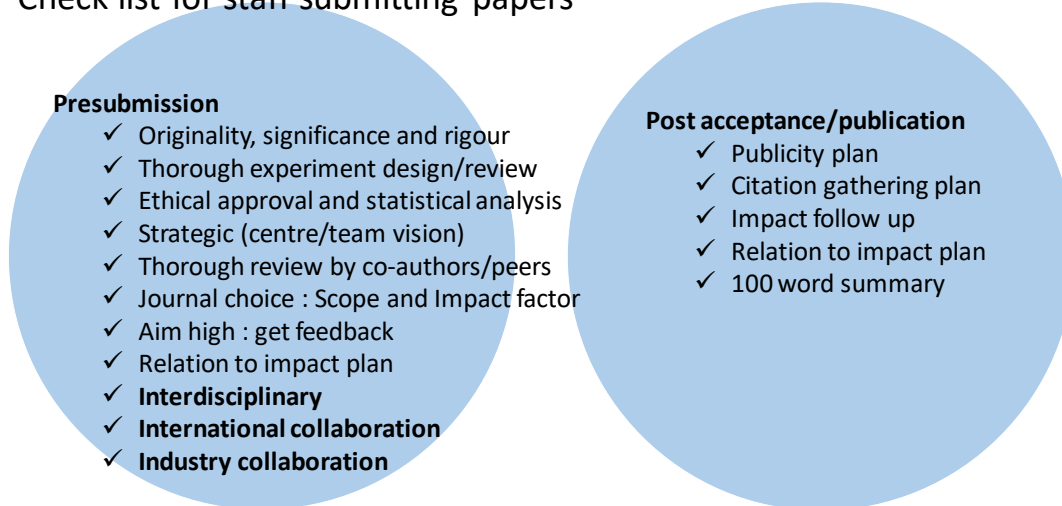


Fig. 1 Checklist for developing research plans and submitting papers as part of our strategy to enhance research quality

- **to increase the number of staff returned in REF2021 by >50% (compared to REF2014)** - through new strategic appointments, ECR development and supporting increased responsibility for research of existing staff, and supporting staff who were more aligned to a teaching pathway to become research active. (see Fig. 2 showing a >75% in staff returned has been achieved)
- **to increase investment in new research infrastructure and resources** - the strategy focuses on building on existing capital including brain imaging/interfacing technologies, living labs, novel technologies for human-computer interaction and high-performance computing infrastructure (we have established a number of new unique labs/facilities (see sections 1.3 and 3.3))
- **to increase the number of PhD researchers by 30%** - through external grant income supported studentships and the creation of an excellent environment for PhD researchers supported through Ulster's Doctoral College. (see Fig. 2 showing a >30% increase in PhDs registered)
- **to increase grant income by 50%** - by targeting large research initiatives, diversification of target funding sources, increased collaboration with international centres of excellence and training staff in grant writing – supported through Ulster's research development programme (RIGOUR (see section 2.1.1)), mentorship by senior staff and staff research profile development (see Fig. 2 showing >54% increase in expenditure)
- **to develop impact** - through engagement with industry, generation and licensing of new IP and commercialisation through the creation of spinout companies, focus on clinical research and trialling technologies with end-users, improving patient care and quality of life, re-enablement of people with disabilities as well as raising public awareness of research science through public engagements and outreach activities (4 spinouts, >£3m KTP funded, multiple research grants with international/industry collaborators and over 70 hospital/clinical partnerships)
- **to excel in multidisciplinary and translational research** - by developing enabling technologies including AI, pervasive computing, software and capability, with a key focus on life and medical sciences and researching the latest emerging technologies across our research themes (interdisciplinary research is evidenced throughout this statement).
- **to ensure staff and PhD researchers are aware of and maintain the highest ethical standards in research** through compulsory training such as our **Research Integrity**

course (100% completion by all staff returned and PhD researchers), with many projects/studies involving human participants ethically reviewed by internal and external research committees.

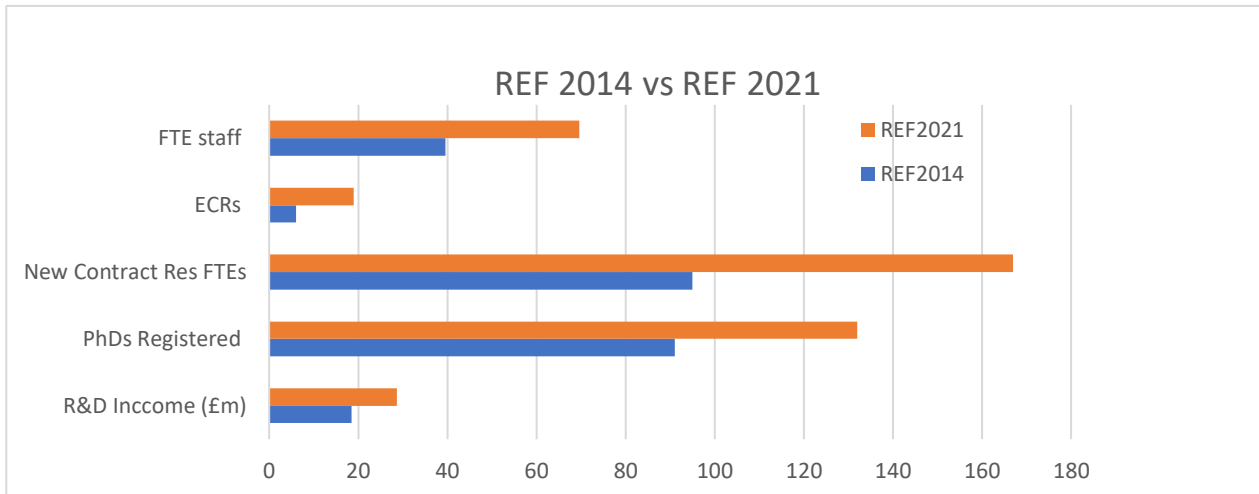


Fig. 2 Indicators of measurable expansion since REF2014 because of our research and impact strategy.

1.2.2 Large initiatives supporting our growth, interdisciplinary research expansion and impact strategy

Industry-led data analytics research strategy

The Cognitive Analytics Research Laboratory (CARL)

- With the growth in demand for AI and data analytics capability locally and globally, as highlighted in the **Northern Ireland Matrix Digital ICT Report 2016 and the Matrix report on AI in Northern Ireland report**, 2019, produced by the Alan Turing Institute, the unit strategically operationalised to consolidate AI research capability across all centres and maximise the exposure of our AI research capability through one **virtual centre, CARL**, in 2017. Ulster University **invested £4m** to create 11 new full-time academic posts for CARL (McCreadie, Ding, Vance, Ramlan, Dora, Rankin, Cleland, Rafferty, Chen, Bai, Bond (promotion)). CARL followed extensive engagement/consultations with industry and civic stakeholders to develop strategy to support industry in their AI and data analytics needs and to enable us to capitalise on the demand for skills and experience in AI.
- The launch of CARL was strengthened through a **£5m endowment by the Dr George Moore foundation** to ISRC, to fund a Dr George Moore Chair in Data Analytics (Kasabov) and research fellowship cum lecturer (Bucholc) along with 3 PhD research studentships in data analytics.

BT Ireland Innovation Centre (BTIIC)

- CARL also coincided with the launch of the **BTIIC (2017)**, a **research and computer science Centre of Excellence**, through investment of **£9m of funding from Invest Northern Ireland** (£6.3m to Ulster) plus a joint investment by **BT and Ulster University of £6,244,427m** in a research programme creating **32 new research positions** (5 fellows, 15 research associates and 12 PhD studentships) at Ulster and **50 new graduate roles** in the **BT Belfast Global Development Centre**. The **BTIIC R&D partnership** is the first in the UK (beyond Cambridge) supported by BT and focuses on building on our unit's strengths in Internet of Things, Intelligent Systems, Cyber Security, Fixed and Mobile Network and telecommunications. The partnership has impacted BT substantially as recognised by the recent award **TM Forum: Winner - Outstanding Catalyst – Business Impact, 2020** (Rafferty, Nugent, Scotney).

The Legal Innovation Centre (LIC)

- **The LIC**, established in 2016, is another example of our strategy of impacting industry through AI capability and interdisciplinary research involving a collaboration between the **ISRC, Ulster Law School, and law firms Allen&Overy and Baker McKenzie** (£250k provided by the Allen&Overy Foundation). The interdisciplinary centre focuses on automation of legal document analysis including extracting facts from prospectuses of companies going public, Automated NDA Risk Analysis, Automation of Company Search Process, and Semantic Fact Verification.

Capital Markets Engineering

- CARL, BTIIC and LIC followed on from a successful **Capital Markets Engineering** project, launched in 2011, involving 10 PhD studentship supported by Invest Northern Ireland (~£236K) and multiple fintech businesses in the region (£420K)
- including **New York Stock Exchange Technologies, Citi, First Derivatives, Fidessa, and Kofax.**

Life and Medical Sciences based research strategy

One of Ulster's 4 priority research themes is **Healthy Communities** and the unit's strategy in contributing to this theme is exemplified in a number of large, funded-initiatives:-

The Northern Ireland Connected Health Innovation Centre (NI-CHIC)

- **NI-CHIC was** established in 2011 as a competency centre (co-led by PCRC and Ulster's School of Engineering) with **£4,627,807 in phase 1** and renewed in 2019 with **£3,359,236** funding in phase 2 **from Invest Northern Ireland (INI)**, to conduct business-led research in the areas of sensors and diagnostics, smart living and analytics and IoT and has led to a membership of over 40 companies and impactful delivery of robust business solutions arising from our research (**impacts highlighted in our REF2021 impact case studies ICS3-6**)
- **Northern Ireland Functional Brain Mapping (NIFBM)** Building on the computational and cognitive neuroscience, neurotechnology and rehabilitation research at the ISRC the **NIFBM** was established in 2014 with a joint investment between Ulster and INI (£5.3m). The facility houses the only magnetoencephalography (MEG) brain imaging system on the island of Ireland. Impactful projects involving trials with patients are **described in ICS1 and ICS2.**

Centre for Personalised Medicine (CPM)

- The NIFBM aligns with the **CPM, established in 2016, through £3.64m received from the EU INTERREG VA Programme (led by Ulster Biomedical Science and the ISRC)**, a cross-border collaboration involving 12 academic partners, public healthcare providers clinical collaborators and healthcare services companies. The objective of the project is to establish a research-led environment for personalised clinical decision-making with ISRC providing neuroimaging, AI and Data Analytics expertise in the project.

Please see sections 2 and 3 for other research grant income that underpin these large initiatives.

1.2.3 Research quality, interdisciplinary research and international collaboration

Through the strategy of focused intensity on securing diversified funding and large industry related engagements along with life and medical sciences and patient focused research, our research quality in fundamental and interdisciplinary research has increased, as evidenced by publications in some of the top journals across a range of research disciplines (see section 4 which shows the distribution of outputs returned in journals across multiple disciplines). The interdisciplinary nature and extent of our research collaborations is evidenced by co-authorship of 125 publications (~72% of those returned in REF2021) with researchers and industrialists from 189 different institutions/companies (150 international and 39 national) and from 33 different countries. Research quality and interdisciplinarity are also exemplified by funding received from multiple prestigious sources including 13 grants from five of the UK Research Councils (5 awards in 2020)

involving interdisciplinary partnerships with other UK institutions (see section 3.1 for further details).

1.2.4 Impact

In addition to realising impact through collaborative R&D with clinical partners (with many patient trials (**all 6 REF2021 ICSs involve patient and/or caregiver impacts**)) and industry across our larger research initiatives (section 1.2.2) the unit has placed significant emphasis on developing and licensing new intellectual property (e.g., **46 new invention disclosures in this REF cycle, 6 patents and 4 licencing deals**) and incubating research to spinout companies (**4 companies founded in this cycle**). Our strategy is underpinned by the belief that pursuing product development and start-ups arising from research within our core research themes will streamline exploitation and impact of current and future R&D and help retain talent and skills within the region to improve the **startup culture, innovation ecosystem and knowledge economy**. Our strategy has been to raise awareness among, and to support, staff and PhD researchers in business development processes and entrepreneurship through:

Business accelerator participation

- supporting staff to participate in top-class business accelerator programmes e.g., (CatalystNI co-founder programmes, NDRC FutureHealth; Ignite at the Judge Business School, Cambridge; RAEng Enterprise Fellowship; IUK iCURE (Callaghan, Coyle, Harkin, Coleman, Kerr).

Product development and startup funding

- supporting staff to bring research beyond published outputs, trialling with end-users and developing prototypes at higher technology-readiness levels through securing INI proof of concept (INIPoC) funding, commercial focused funding and equity investment for spinouts. For example, following proof-of-principle Ulster funding (£10K, 2012), INIPoC funding (£106k, 2013), a **Royal Academy of Engineering Enterprise fellowship** (£60k, 2016), Ulster spinout **NeuroCONCISE Ltd** (neurotech company) was founded (2016) and secured two **Innovate UK Grants** valued at £340K (**Project Nos. 103607, 104959** and seed investment of £210K from **Techstart NI and Innovation Ulster Ltd**) (linked with ICS1). Another spinout **Respiratory Analytics Ltd** (previously SmartAir and Airbrio Ltd) secured an **IUK Smart Award** (£310K **Project No. 56551**) and £180K equity investment. Software emerging from research in the Total Energy Management for Production Operations (TEMPO) project went on to secure INIPoC for smart energy analytics software (iTEMPO) (2018) and subsequently, Innovate **UK funds from the ICURE programme**. Research in gait analysis also secured INIPoC funding (eZiGait, 2019, Zheng). Research in bioinspired computer vision (**VISUALISE** project) received INIPoC leading to spinout company **BIONICS**.

Section 4 presents further information on impact through collaboration involving Knowledge Transfer Partnership funding (**>£3m this REF cycle**) and partnerships with over 70 hospitals/healthcare providers.

1.3 Future strategy

Our future strategy has four overarching themes that will enable us to grow our research capacity, intensity and quality:

- People - Talent/skills;
- Infrastructure;
- Research Resources;
- Open Data

1.3.1 Future People - Talent and skills,

Building on the strengths of the unit and the significant growth of the unit in this REF cycle, we aim to consolidate and strengthen our existing staff cohort in the next REF through a number of large, targeted research initiatives that link with local and national strategies which are already in

development, industry-led challenges in AI and Data Analytics and Life and Medical Sciences to build capacity including:

- **AI Collaboration Centre for Northern Ireland (AiCC-NI):** building on the recommendations from the Turing report on AI capability in Northern Ireland and the UK AI strategy, this CS@Ulster-led collaboration with Queens University Belfast will develop AI capability and awareness, enable industry upskilling and deployment of AI across a range of industry-led data analytics challenges (outline business case to be submitted to the Department for Economy March 2021). AiCC will build on a **Seagate-led project, SmartNanoNI**, which has secured **UKRI Strength in Places Funding** (first stage), involving multiple partners including the ISRC, Coyle's **Turing AI Acceleration Fellowship (EP/V025724/1)** secured in 2020 which has a time allocation to translate AI developments from neurotechnology research to other industry sectors and a further **£500k invested in the Legal Innovation Centre by Allen&Overy** in 2020 for AI related research.
- **Operate Technology Innovation Centre (OpTIC):** PCRC engaged with **Price Waterhouse Cooper (PwC)** to as part of PwC's longer-term strategy for R&D investments across the UK and globally over a 10-year horizon, with a particular emphasis on Robotic Automation, Workflow Automation, Data Analytics and Artificial Intelligence. **£6.8M funding has been approved by Invest Northern Ireland (March 2021) to establish OpTIC.**
- **BBC Data Science Research Partnership (DSRP):** Ulster University is one of eight UK universities to form a major five-year (2017-2022) research partnership with **BBC Research and Development** to unlock the potential of data analysis in the media. In 2020, AIRC (Wang, PI) secured along with BBC NI, Cambridge University and Surrey University, £2.24m funding from **EPSRC (EP/V002740/1, £720K to Ulster)** for Multimodal Video Search by Examples. A number of other data analytics projects are being developed in **BBC-DSRP.**
- **Accelerating Ireland's Neurotechnology Growth (ACING)-Institute:** building on growing strength in neurotechnology, computational neuroscience and neuroimaging R&D and infrastructure in ISRC the ACING institute will capitalise on the UK push to become leader in neurotechnology innovation through the **KTN Neurotechnology Innovation Network** (Coyle, Advisory board member), addressing the UK EPSRC Healthcare Technologies Grand Challenges and Ireland North-South Collaboration funding, with all major neuroscience/neurotech research centres in the Rep of Ireland as well FutureNeuro and NeuroNSIGHT. Appointments to support this development include **Kelso, Bhattacharya, Wade, Liu, Flanagan, and Kasabov.** ACING will be supported by recent grants including the **UKRI Turing AI Acceleration Fellowship: AI for Intelligent Neurotechnology** (EP/V025724/1, ~£1.8m, Coyle, 2021-2025) and **two US-Ireland R&D** grants both part-funded by UK **MRC: MC_PC_20020** (£175k to Ulster, Wong-Lin, 2020-2025) with Columbia University, New York and University College Dublin and **MC_PC_20021** (£389,995K to Ulster, McDaid, 2020-2023) with Kansas State University and NUI Galway.
- **COVID19 related research:** We will continue to play our part in understanding and treating COVID19 through funded projects including EPSRC project EP/V026488/1 **Virus Identification via Portable InfraRed Spectroscopy** with Queen's University Belfast, Northern Ireland Regional Virus Lab, Technical University Dublin (£410K Wang, 2020-2022); and the **DfE-SFI-funded COVRES project** (SFI Ref 20/Cov/8581, £354,637, Bucholc). Bucholc has a public health agency (PHA) Research Placement Agreement (REF: 20200528) to conduct analysis on the risk factors for mortality in patients with COVID19 and research into COVID19 using the **UK COVID-19 Symptom Tracker** data to assist the work of the **UK Government Specialist Modelling Response Expert Group (REF-SAIL: 1131).** Bucholc also developed the **COVID-19 Tracker app for Northern Ireland** (<https://nicovidtracker.org/>).
- **Doctoral training:** A major emphasis in the next REF cycle will be on expanding our PhD research cohort targeting an EPSRC centre for doctoral training, industry supported studentships and other doctoral funding initiatives such as European Training Networks e.g., **H2020-MSCA-ITN-2015 project ACROSSING** (Chen, Nugent, Cleland, McCullagh).
- **Researcher mobility:** We will continue to work with the international centres of excellence building on, for example, **PRO-GAIT** (Coyle), **SenseCare** (Zheng), **MetaPlat** (Wang) and **REMIND** (Nugent), **MENHIR** (Bond), all staff mobility programmes supported by the **H2020-MSCA-RISE.**

With the larger unit size (69.6fte) and these initiatives we will increase research intensity through an **increase in the number of PhDs completions/year by 30%** (via additional studentships and a route and branch analysis of processes to improve in PhD completion rates) and **double the number of contracted research staff hours** in the next REF cycle.

1.3.2 Future Infrastructure

There is a substantial funding commitment for research facility expansion and capital through two major regional development initiatives i.e., **City Deals**, which are a once in a generation investment package to accelerate inclusive economic growth. CS@Ulster is in an excellent position having a leading role in two separate City Deals. Key infrastructure projects led by or associated with CS@Ulster include:

Derry/Londonderry and Strabane Region City Deal (Total investment package £250M)

- **CARL (lead) – The Cognitive Analytics Research Laboratory (total value £16.5m)** will establish physical presence for a research and innovation centre dedicated to cognitive analytics and AI and enable our growth plans for **CARL virtual** established in 2017 and the proposed **AiCC** as well as expansion of the ISRC's core research themes which underpin new AI developments for industry-led data analytics challenges.
- **CIDRA (lead) – The Centre for Industrial Digitisation and Robotics Automation (total value £25.5M)** will be a centre of excellence for Industry 4.0 enabling the manufacturing industry to become more innovative, productive and competitive in their operations through the adoption of emerging digital technologies and AI.

Belfast Region City Deal (Total investment package £850M)

- **CDHT (partner): The Centre for Digital-Healthcare Technologies (total value £42.9M)** will bring together capabilities in Computing (AI, data analytics to IOT), Engineering (Health Tech. to Connected Health) and Biotechnology (Molecular Diagnostics) to build additional capability, a world class innovation accelerator and co-creation platform and technology cluster, for academia, industry and clinicians to innovate and boost the healthcare technology sector.

All our City Deal project initiatives are associated with AiCC outlined above and focus on new buildings and new state-of-the-art research equipment and future proof and drive our growth strategy and will enable us to continue to develop world-class research infrastructure. **Business Cases have been approved and Heads of Terms have been signed off by government for both City Deals.**

The city deals will follow-on from a **new Ulster Campus development (The Greater Belfast Development) with an investment of £365M which is due to open in 2021.** AIRC and PCRC will be relocated to state-of-the-art research labs and facilities on the new campus.

1.3.3 Future Research Resources: to grow new research themes skills, talent and capability To ensure we undertake interdisciplinary research at the cutting-edge we have established or augmented research equipment in a number of novel areas in 2020. We aim to build capacity in these areas in this next REF cycle including (see section 3 for additional detail):

- **The Spatial Computing and Neurotechnology Innovation Hub (SCANi-hub, 2020) (£266,277, Department of Economy):** Establishing new research that involve electrophysiological computer interfaces and virtual and augmented reality (linked with Turing AI Fellowship EP/V025724/1 and Impact Case Study (ICS1).
- **Tier 2 Northern Ireland High Performance Computing Facility (NI-HPC,2020) (£2.1m, EPSRC):** A cross disciplinary resource and project with a core focus of increasing HPC usage from the current ~30% of researchers within the unit to 90% of researchers in the next REF cycle – part of our strategy to enhance research quality/productivity.
- **Northern Ireland Functional Brain Mapping Facility (NIFBM, 2016) (£5.3m, Invest Northern Ireland):** Having completing a 5 year programme (phase 1 (2014-2020)) to establish the NIFBM, the next REF cycle will see our growth strategy engaging the 500+ neuroscience research across the island of Ireland (phase 2 (2020-2024)) to undertake

research at the facility, followed by a self-sustainable growth plan for a **clinical MEG and neuroimaging centre of excellence** (phase 3 (2024-2029))(ref ICS1 and ICS4)

- **Hyperspectral Imaging Facility (HIF, 2020) (£30k funding through Ulster/SoC strategic investment):** Spectroscopic data collection facilities that cover the full IR range augmenting a state-of-the-art hyperspectral camera (Specim FX10) to support the expansion of research in spectral pattern recognition and its applications e.g., food authentication and more recently coronavirus detection (**EPSRC project EP/V026488/1**).
- **Connected Health Living Lab CH:LL:** With University's investment in The Greater Belfast Development (see 1.3.2) CH:LL will be moving to the new campus facilities and will be completely renewed and modernised.
- **Integrated-Diagnostics-Laboratory (IDL) (£339K, 2020)** Department of Economy, NI. Integrated-Diagnostics-Laboratory (IDL), a core part of CDHT (City Deal project above) will integrate with the CH:LL and have an emphasis on clinically led, innovation in new medical device development.

Our strategy is aligned with the **Government UK R&D strategy** ranging from investment in research, entrepreneurship promotion and attracting, retaining and developing diverse and talented teams, ensuring Northern Ireland participate fully in the **UK levelling up agenda**. We will contribute to **addressing the Government's AI and Data Grand Challenge, accelerating adoption of AI technologies and attracting inward investment in AI** and to the **UK AI Sector Deal** which aims to **grow the UK's AI sector** with specific focus on supporting **UK AI Council** mission and **UK AI Roadmap** (Maguire and Coyle as working group members) which has a focus on AI for health, on the basis that making the UK great at AI in Health would benefit the wider economy and society. The recommendations in the recent report on **AI Research in Northern Ireland** produced by the Alan Turing Institute are being pursued through the initiatives outlined above and we aim to be the key underpinning driver for the **Northern Ireland Industrial Strategy**.

1.3.4 Supporting Open research

CS@Ulster has developed an Open Research Working Group alongside a University wide Open Research Working Group to embed open research practices in the research lifecycle focusing on

- Promoting openness across the research lifecycle
- Ensuring all PhD and funded projects have data curation plan to make data open and accessible
- A University managed repository for open access to outputs e.g., PURE.
- Compliance with Concordat on Open Research Data.

~**26%** of the 174 the units outputs returned **are available in Gold Open Access**. Paper preprints are made available, for example, 10 outputs are available in bioRxiv. Our funding strategy for the next REF cycle will enable us to **increase Gold Open Access to 80%**. We have a number popular open datasets e.g., the Pratheepan Dataset (Pratheepan, Condell) and open code e.g., AutoAPI, Moore) and aim to make **>50%** of all code and data open in the next REF cycle. Our PhD theses are available in open access format in the institutional repository since 2017. Ulster has signed the Plan S compliant transformative agreements where possible and recent 'read and publish' agreements have been signed by the library and several publishers.

2 People

2.1 Staffing strategy

Our staffing strategy has been to develop strong and diverse leadership, reward staff through supporting application for promotion and awards, develop contract research staff and increase the intensity of research active staff. A major focus of the staffing strategy was to grow expertise in AI/Data Analytics through the CARL initiative and target new appointments that complement existing research themes to build capacity in priority areas.

The demographic profile across CS@Ulster is well-balanced, with 14.6 Professors, 6 Readers, 10 Senior Lecturers, 32 Lecturers and 2 Research Fellows in this submission (overall median age 47 years). This **includes 19 ECRs (median age 34) (a >17% increase in ECRs since REF2014)**. Whilst 10 staff returned in REF2014 have left through retirement, career change or to other institutions, recruitment of new staff, including ECRs, has been a strategic priority, along with increasing the research responsibility of 10 existing staff who were not returned in REF2014 (Wang, Sterritt, Nicholl, Wallace, McChesney, Santos, Moore, Uhomobhi, Black, Mulvenna). This strategy has resulted in a **>75% increase** in the size of the Unit to 69.6 fte : ISRC: 30.9 fte (21% female); AIRC/PCRC: 38.7 fte (17% female).

A pervasive international culture

CS@Ulster has a diverse and international culture with **50% of our staff (37 fte) being non-British** including Irish (23%), Chinese (10%), Indian (4%), Italian (3%) and 9% Algerian, Bangladeshi, Bulgarian, French, Malaysian, Polish, Singaporean, Spanish and Sri Lankan. CS@Ulster sustains a programme of strategic appointments of international renowned professors on 0.2fte contracts to enhance leadership and collaboration in strategic areas, **Kelso** (computational neuroscience/complex systems, re-appointed), **Kasabov** (AI/ neurotechnology) and **Paggetti** (digital health).

Leadership development

A supportive research environment has enabled staff to develop leadership in strategic areas and obtain **professorial promotions** since REF2014 including: Coyle (Neurotechnology, Director ISRC), Coleman (Cognitive Robotics Theme lead), Curran (Cyber Security and Web technologies theme lead), Condell (Intelligent Devices) and Zheng (Bioinformatics) i.e., **60% of Professorial promotions were female evidencing our EDI strategy to support female staff**.

Staff promotions

Other academic staff **promotions since REF2014** include: to **Reader** (Callaghan, Harkin, Wang, Liu, Bi, Bond, Wonglin); and to **Senior Lecturer** (Gardiner). Ulster has a recently revised process for recognising and rewarding academic excellence. Applicants for promotion can occur at any point in the year. Staff on the research and impact pathway for promotion are assessed on their outputs, income/grants, mentoring and research supervision, esteem, impact, and leadership.

Recognition of achievement

In addition to promotion staff are recognised through **University research awards** which include financial support to awardees, e.g., **early career excellence awards** (Cleland, Bucholc.), **distinguished fellowship award** (Bond, Wonglin) and **senior awards** (Prasad, Nugent). **Ulster's sabbatical leave programme** is available to support all staff (e.g., Wonglin).

Concordat to support the career development of contract researcher staff (CRS)

Increasing the number of CRS through targeting funds that support projects which enable longer term CRS appointments has been a key mechanism to expand our strategic research focus. **Since 2014 a total of 175 fte new contract research posts have been created**: 89 in ISRC; 86 in AIRC/PCRC. The importance of recruitment, selection, retention and career development for CRS are recognised via the Concordat, with annual opportunities for advancement, regular training and development provision. Ulster received the **HR Excellence in Research Award in 2012 and retained the award following Vitae reviews (2014, 2017 and 2019)**. Our action plan ensures

that we continually improve the career development of CRS and adhere to the 3 Concordat principles, offering CRS up to 10 days of internal/external training programmes. **CS@Ulster staff member (Bond) is Ulster's (University Level) Research Concordat Coordinator.**

2.1.1 Induction and staff training

CS@Ulster leverages the training support provided by institutional schemes. Local Induction is provided for new staff along with an interactive Online Welcome and Orientation Programme. University wide support programmes include: **RIGOUR (Research Income Grant Opportunities for Ulster Researchers)** – a programme to enable better understanding of funder requirements and proposal writing/impact/costing, and access advice from successful grant awardees (**staff attended 101 RIGOUR events**); **SOARING (Significance and Originality in Academic Research: Interpreting New Guidance)** – a programme that helps academics/researchers develop a better understanding of producing internationally excellent and world-leading outputs (**staff attended 45 SOARING events**); and, **IMPACT**, a programme to enhance the impact of research, impact evidence and/or define pathways to impact (**staff attended 29 IMPACT events**). In summary, **~68%** of our staff participated in 175 research training events and **~70% of our ECRs** participated in training events. Staff are offered programmes such as Leadership and Management Development, Coaching and Mentoring, and Organisation Development.

Senior researchers support staff in developing grant applications by reviewing their draft proposals and a **mentorship scheme** pairs senior staff with ECRs who assess the ECR profiles and co-develop strategies to address profile areas in most need of development (**~35% staff participated in the research mentoring programme**). For PhD supervision, ECRs are paired with staff who have a record of successful supervision. A target is to ensure all new ECRs are supervising at least one new PhD researcher in the first year of joining the unit.

2.1.2 Staff development

An annual budget (~£100K/annum) is devolved to the unit RDs, based on QR income and overheads recovered from external funding. This is used to strategically support staff develop their research profile by attending conferences/workshops, travelling to develop research partnerships, hosting/organising events, and participating in scientific committees, open access publications fees, and strategic think-tank days among other initiatives. These funds are supplemented by additional funding (devolved from Faculty budgets) to address the faculty led targets and KPIs e.g., assisting ECRs or initiatives to increase citations and raise awareness of research quality e.g., **Citations Increasing by Team Engagement (CITE)** competition; and supporting research that involves co-authoring with international centres of excellence and industry partners (see section 3 and 4 for evidence).

The University provides additional strategic internal support funding through competitive initiatives, funded in part, by DfE NI, INI and other bodies (see section 3).

Unit RDs, supported by Heads of School, hold individual meetings annually with staff to help develop their personal development plan, which is reviewed by mentors, and objectives and targets agreed. The data in Fig. 3 are presented yearly for each staff member **to assess progress and where their profiles can be improved**. Teams (or groups) also work together to create yearly research plans including specific plans for funding and growth strategy and sustainability of research and each of the three research centres plan to target at least one multimillion pound initiative yearly.

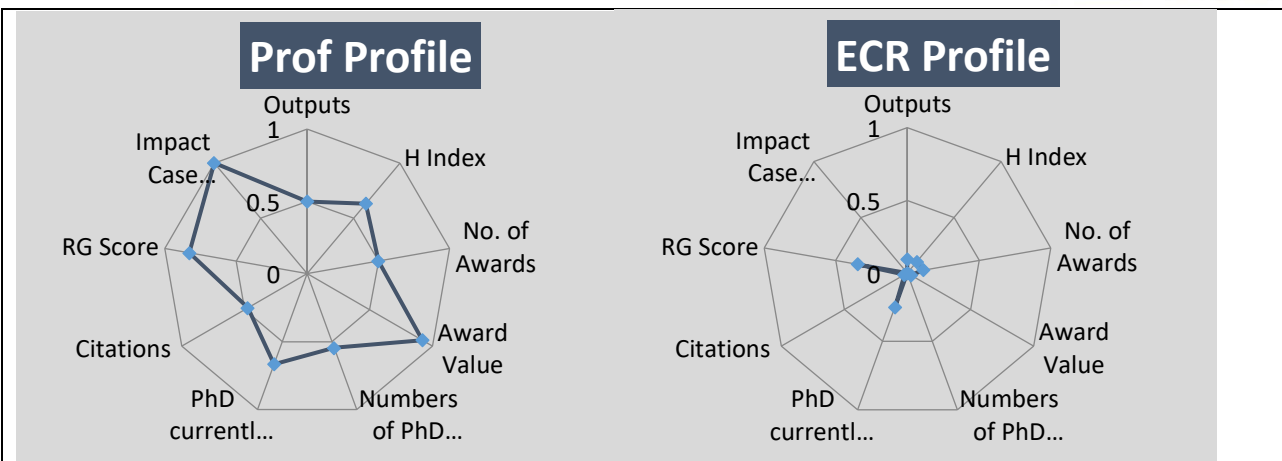


Fig. 3 Staff profile to identify areas of profile improvement

Externally facilitated design-thinking led workshops have been organised **to review and renew research centre vision/mission statements** and develop strategies to realise vision/mission as well as best practice on time management and prioritising research. Staff also participate in regular seminars (e.g., in this REF cycle the Unit has held **58 invited speaker seminars involving visiting researchers from 12 countries** e.g., Viktor Jirsa, Head of CNRS Neuroscience in Marseille 2019). Additionally, our Research & Impact Office provide a Researcher Development Training Programme of events to support staff and ensure compliance with research governance through a **compulsory Research Integrity course (100% completion by all staff/PhD researchers)** and an **Online Data Protection training programme**.

2.2 Supporting Equality, Diversity, and Inclusivity

CS@Ulster upholds Ulster University's policies and procedures for equality, diversity and inclusivity (EDI) as outlined in our institutional level environment statement. Ulster is a member of the **Athena Swan Charter to promote equality for women in STEM subjects**, and both schools in the unit hold **Athena Swann Bronze awards**. We have a strong EDI ethos, recognising, valuing and capitalising on people's differences and strengths. Diversity and inclusivity are valued, actively promoted and embedded in all research processes and policies as outlined in our Code of Practice, which places people at its centre and ensures barrier free processes to maximise inclusivity and participation in REF and was used as our roadmap for identifying SRR staff and selecting outputs for REF2021. We support equality of opportunity through open communications to staff about strategic initiatives, funding opportunities and training, and via a maximum teaching load policy of 180 hours per annum. We support e.g., **Wo/men's Network events** which provides a supportive and collegiate space to, build relationships, encourage personal and professional learning; and recognise and celebrate the achievements of women. Female staff have also engaged in **Aurora**, a leadership development programme for women, who demonstrate the ambition to develop leadership responsibility (e.g., Rankin). **With 9 new female appointments in this REF cycle, ~19% of our staff are female (up ~27% since REF2014), ~48% of our current PhD cohort are female (up 45% since REF2014). We aim to encourage female PhD researchers to consider academic positions (e.g., Ding, Rankin, Bucholc, Flannagan).** Our interviewer panels are gender mixed. We ensure all staff are recognised as playing a central role in achieving our ambitions through **Supporting Performance, Strengthening Engagement, Promoting Wellbeing, and Developing People with Positive Employee Relations within research teams and when engaging with partners and collaborators.** As part of Ulster's Athena SWAN Action Plan (2017-2021), a **Returning Carers' Scheme (RCS)** was established to financially support all academic/research staff on return from extended leave (normally 4 months or more) for reasons connected to caring for dependents (Zhang, Condell, Brown). Ulster is a member of **Advance HE's Race Equality Charter**, which aims to improve the representation, progression and success of minority ethnic staff. Ulster has **signed the San Francisco Declaration on Research Assessment**, committing to the principles of fair, responsible and open use of metrics in the assessment of research when recruiting/promoting staff and upholds the principles of the Leiden Manifesto and the Metric Tide.

>35% of funded projects our staff are involved in are female-led and >15% of funded projects are led by international staff. We encourage project PIs to consider gender balance on project management teams and steering committees.

2.3 Unit research support structure

We have an excellent research support structure within the unit. Fig. 4 shows how each school in the unit is organised with two **RDs (Coyle, Chen)**, two **Postgraduate Tutors (PGT) (McCreadie, Cleland)** and **Two Academic Excellence Executive Assistants** dedicated to research. Each PGT works alongside each RD and exec assistant to ensure the PhD researcher experience is top-class by being accessible and responsive to solve issues rapidly and to provide excellent pastoral care. A dedicated **research software engineer (RSE) (EPSRC funded see section 3.3))** provides HPC training/support for all researchers. Each school's **Research Executive** is chaired by the RD and includes centre/teams leads. Meetings are held as required to develop strategy and address research opportunities/challenges. RDs, Centre Directors and Theme leads work collaboratively across the unit to ensure cohesion and complementarity between research centres.

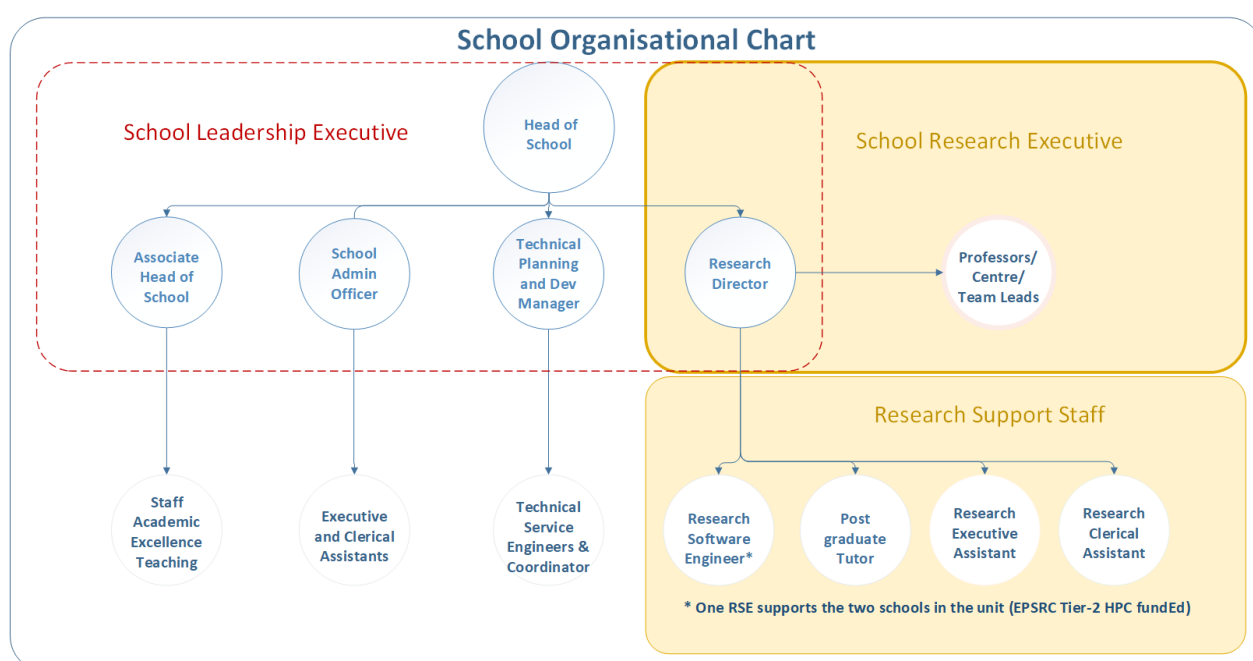


Fig. 4 – Schools Organisational Chart and Research Supports structures

2.4 Research Students: Recruitment, Training and Support Mechanisms

2.4.1 PhD recruitment

During the REF cycle Ulster established a **Doctoral College (DC)** which supports all units and is responsible for research student registration, maintaining records and monitoring PhD researcher progress and training. RDs are responsible for recruitment, quality assurance and maintenance of standards, within procedures established by the DC (**see section 3.1 for PhD studentship funding**). PhD project proposals are presented by teams/staff with criteria applied to ensure proposals are strategically aligned with research themes, ECRs supervise a PhD within 1 year of joining, projects can be completed within 3 years and project descriptions are written to attract candidates of the highest calibre. Up to 3 project proposals are advertised per available studentship. A robust recruitment process is undertaken to allocate research studentships through open competition and interview. Interview panels (one per school) are chaired by the RDs and involve the PGT and centre/team leads.

2.4.2 PhD training and support mechanisms

All new PhD researchers undertake DC induction and local induction at unit/centre level which covers training opportunities, the research process, research activities within research centres, expectations, and REF among other topics. All PhD researchers can access Ulster's **Researcher Development Programme** which has >150 training courses designed for researchers and guided by the Vitae Researcher Development Framework. All PhD Researchers are encouraged to undertake the equivalent of 10days/year in researcher development activities.

All full-time PhD researchers have an allocated individual office desk and access to state-of-the-art research facilities (see section 3). A training budget of ~£900/annum is provided to purchase networked PCs/laptops for each new researcher and for additional training/development, attending conferences/workshops/courses and is often supplemented by ad-hoc training funds or externally funded projects.

The Ulster PhD journey (and PhD Manager): the PhD journey was developed to ensure a consistent, university-wide approach to postgraduate research education/training. Clearly established milestones (**see below**), annual reviews and close monitoring by PGT within each UoA have yielded improvements in PhD researcher satisfaction (**see PRES results below**). **PhD Manager** software streamlines the paperless monitoring process.

The RDs/PGTs jointly review annual student and supervisor reports, assessing resource/ progress issues. Annual assessment procedures include: **Year 1**, an initial assessment report/viva (within 3 months of start) and a confirmation report/viva plus a paper drafted, to confirm PhD registration within 12 months; **Year 2**, PhD researchers present posters at the annual Faculty Research Dinner; **Year 3**, PhD researchers present at the **Annual Festival of Research** and receive feedback from senior researchers from several disciplines as part of final assessment (prizes awarded for the best). PhD researchers compete in the UK's **3-minute thesis (3MT) competition** (Harrigan, Reid). PhD researchers are strongly encouraged to publish and use peer reviewed feedback to achieve appropriate postgraduate standards and timely completion. At the Annual Faculty Research Dinner (latterly University Research Dinner), the unit awards four PhD prizes: **Best thesis, paper, confirmation report and poster**.

Supervisor Development: Our DC offers training on PhD researcher supervision through its **Supervision Development Programme** covering e.g., supervisor-PhD researcher relationship and ensuring the best PhD research experience.

2.4.3 PhD researcher experience

Our PhD cohort has grown 45% (REF2021 vs REF2014 census date). The **Postgraduate Researcher Experience Survey (PRES) 2019** highlights the quality of our PhD researcher experience i.e., scoring in the top percentile on all scores (except research skills at the 2nd percentile, although achieving 90%) out of 34 HEIs surveyed. Notable achievements by PhD researchers in the Unit include the **Convocation student of the Year Award in 2019** (Atiya); Best Rapid Presentation at NSRF Virtual Seminar on Suicide, Self-harm and Mental Health (Turkington); 2019 Paul Dudley White International Scholar (Torney), Christopher Mills Award 2020 (ITP) (Rabbani), 2nd Prize AI Northern Ireland Datathon 2019 (Roy and Cichy supported by CRS Sanchez-Bornot and Vibhakar), IEEE CIS Student Research Grant (Behera) and 3 Santander Mobility Awards (Korik, Flannagan, Shewell).

3 Income, infrastructure and facilities

3.1 Research funding and strategies for generating research income

Our strategy for increasing research income has been to:

- diversify our target funding agencies
- emphasise impact and applied research funded through large grants and strategic investments (as outlined in section 1)
- target prestigious rigorously reviewed initiatives for cutting-edge fundamental research
- develop key infrastructure/research resources to support cutting-edge research and our growth strategy.

We have secured over 250 grants of varying values from over 130 different sources/programmes. In this REF cycle CS@Ulster has secured £52m (ISRC ~£19m, AIRC/PCRC ~£33m) grant income. **Research expenditure has grown by 54%.**

As evidence of our collaboration efforts and multidisciplinary research success we have secured **13 grants from 5 of the UK research councils (5 secured in 2020 listed in future strategy section 1.3.1)**, 10 of which involve collaborations with other disciplines and partnerships with 8 UK Universities and US and Irish Universities:

EPSRC:

- EP/M01214X/1 **Feasibility of cognitive based Computer Aided Engineering Design**, with Strathclyde University (£147,142 Coyle, total ~£1.06m, 2015-2019).
- EP/N00714X/1 **Self-repairing hardware paradigms based on astroYecyte-neuron models**, with York University (£375,835 McDaid, total ~£1.06m, 2015-2019).
- EP/P031668/1 **Algorithms on rank aggregation for preference orderings**, (£100,980 Lin, 2017-2019).
- EP/T022175/1 **Tier 2 Northern Ireland High Performance Computing Facility Kelvin-2**, with Queens University Belfast (£494,698K, Coyle, total ~£2.1m, 2019-2024).

BBSRC

- BB/P003427/1 **Large-scale recording and computational modelling of midbrain raphep microcircuitry during emotional learning**, with Oxford University (£192,572 Wonglin, total ~£611,895, 2016-2020).

ESRC-BBSRC

- ES/N000323/1 **EpiFASSTT: Epigenetic effects on children's psychosocial development in a randomised trial of folic acid supplementation in second and third trimester**, with other units in Ulster (£400,337, Prasad, 2016-2019).

AHRC

- AH/S002855/1 **Future Screens NI**, with Queens University Belfast and other Ulster Units (~£5.7m to Ulster, Charles, 2018-2023).

ESRC

- ES/T004983/1 **Birth across the Borders – exploring contextual education as a catalyst for improved maternal health**, with other units in Ulster (£1.76m, Nugent, 2020-2023).

Other prestigious grants include two **The Leverhulme Trust/Royal Academy of Engineering Senior Research Fellowships** (Coyle and Curran), a **Royal Academy of Engineering Enterprise Fellowship** (Coyle) and grants from **Royal Irish Academy** (1), the **Royal Society** (2), **British Academy** (2) the **British Council** (2), **DSTL/MOD** (3).

Unit-level environment template (REF5b)

Our staff have secured **26 EU FP7/H2020 grants** including MSCA Research Innovation Staff Exchange, Innovation Training Network, ERASMUS and pre commercial procurement (PCP) (see section 1.2.3 and 4.1) and **12 INTEEREG NPA/V/VB/ grants**.

Other international collaborative grants include from the **European Space Agency (2), US/Ireland Programme (tripartite grant)(3), Human Frontiers Program (1), UK-India Education and Research Initiative (2)**.

We have secured support from **Health and Social Care Trusts Northern Ireland (13)** and multiple foundations/charities including **Foundation for Research in Rheumatology, CME Group Foundation, Dr George Moore Foundation, Macmillan Cancer Support, Samaritans Enterprises Limited and The Templeton Foundation**.

Pump-priming research grants

Staff have received **8 Global Challenge Research Funding (GCRF) pump-priming awards from the Department for Economy**, totalling £180k and **7 University-funded Civic/Commercial Impact priming grants**, to enable network building, pilot project targeting larger funding initiatives and establishing proof of concept and product prototyping.

PhD funding

Most studentships are supported by the **University's Vice Chancellor's Research Studentship** programme and the **Department for Economy**. (DfE awards are treated as equivalent to RCUK awards; VCRS are open to overseas candidates). **Studentships funded by industry partnerships and foundations** include BTIIC (12), Dr George Moore endowment (3), Digital Natives, Jordan (1) Capital Markets Project (4), CME Group Foundation (1), and DfE/EPSC CAST/CASE awards with Clinisent, Treze Ltd, Seagate Technologies (1), ClickEnergy (1), CHIC (2), DSTL (2), Datactics (1), Intel (1) and Scotland's Rural College (1).

Interdisciplinary PhD studentships: Ulster's DC organises a competitive studentship allocation process for interdisciplinary projects where supervisors from two or more UoAs (different disciplines) propose cross-disciplinary research project. Since the programme began in 2016, 28 studentships have been awarded and **CS@Ulster staff have been involved in 50% across 18 other UoAs (leading, ~29% or co-supervising, 21%)**, evidence of our commitment to and capacity for **interdisciplinary research and doctoral training**.

Impact of research funding – team expansion and research quality

Diversified funding streams has enabled, through intense focus on collaborating broadly across disciplines, our research centres/themes to grow substantially (see section 1 for growth). For example, since REF 2014 **ISRC research themes have evolved and now include an additional dedicated Intelligent Data Analytics team (now the largest theme within ISRC with 10.2fte)** focusing on AI and agile capability to deal with industry-led challenges. **Two new research centres have been created, AIRC arising from the AI research group (REF2014) and PCRC arising from the Smart Environment Research Group merger with Information & Communication Engineering (ICE) since REF2014**.

Taking a metric-informed view, our successful research and funding strategy has resulted in **improvement in research intensity and quality as evidenced by papers published in the top 10% of journals (Fig. 5) across a range of disciplines (Fig. 6)**. The average citations per output returned has increased by **~100%** since REF2014.

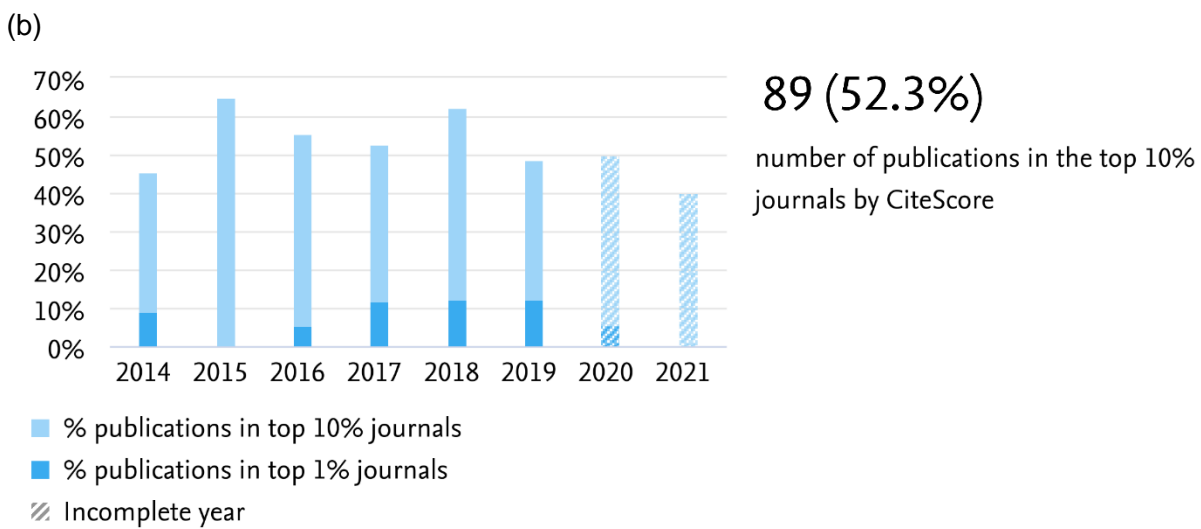
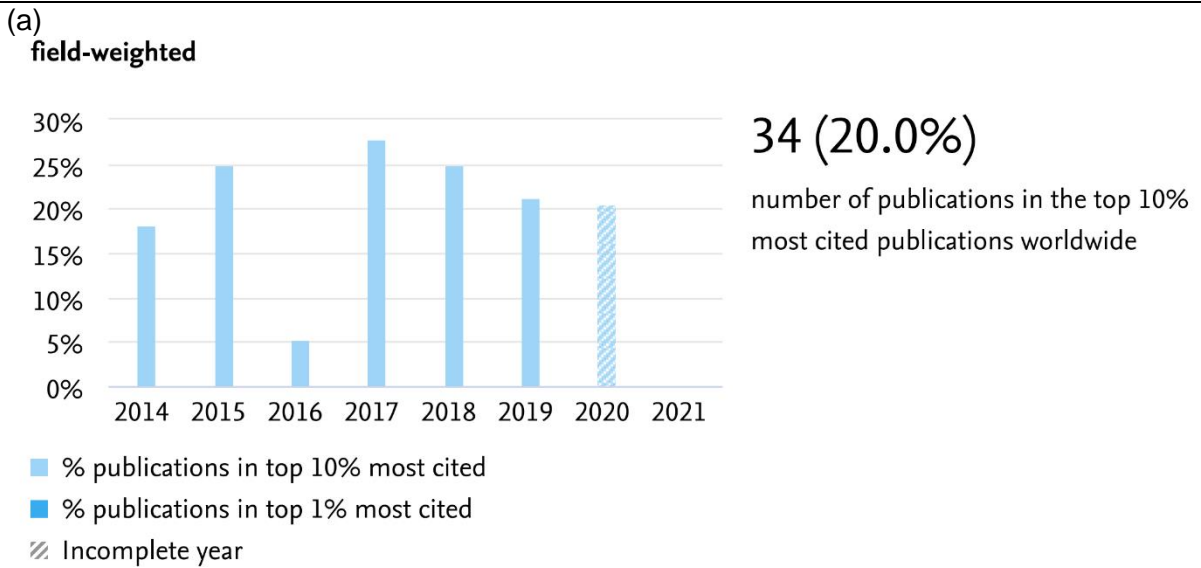


Fig. 5. See legend for (a) and (b) – data is taken from Scopus 16th March 2021 and based on **outputs returned in REF2021**. (NOTE: excludes 4 papers most recently published and not yet in the Scopus database).

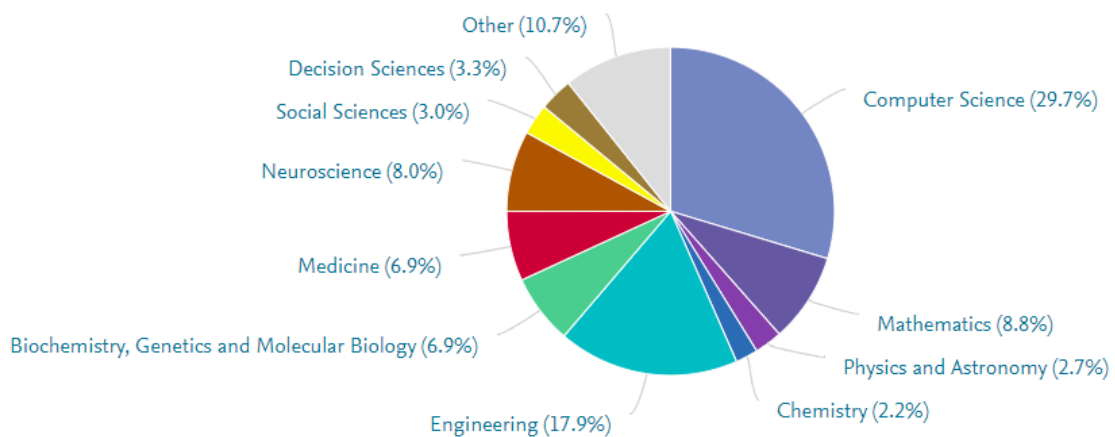


Fig. 6. the data is taken from Scopus and based on 170/174 outputs **returned in REF2021** and **reflect the diversity and interdisciplinarity** of our research.

3.2 Research support

Research project management is supported within each school through the structure highlighted in section 2.3. This is supported through University Research Development team which is Faculty-facing and includes dedicated Faculty Research Managers, Global Manager and a Strategic Research Development Manager to help identify the most appropriate and prestigious funding opportunities. Together with the Research Management team these teams provide a continuous and effective pre- and post-award service to our unit. The Research Development team work closely with Global Engagement and Development & Alumni Relations, faculties Associate Dean for Research & Impact and RDs to identify partnerships to strengthen funding applications, leverage financial support to promote and identify opportunities for interdisciplinary research collaborations, PhD match funding is offered to support strategic grant applications.

3.3 Specialist infrastructure and facilities

3.3.1 IT and High-Performance Computing (HPC)

Within the unit we provide all researchers with HPC resources including a cluster with 672 compute cores and a NVIDIA GPU cluster containing 8 Tesla V100 compute nodes. These **Tier-3 services** enable onboarding of HPC users locally. A partnership between Ulster (Coyle) and QUB has established a state-of-the-art national **EPSRC funded (£2.1m) Tier-2 HPC Facility for Northern Ireland (Kelvin-2), one of only 7 Tier-2 UK national centres**. The Northern Ireland HPC contains 8000 AMD-based CPU cores, 32 GPU Tesla V100 nodes and 2 Petabyte of scratch storage interconnected via a high-speed network. A **research software engineer** works alongside researchers to develop complex code pipelines for optimisation, simulation and analytics with a focus on bioinspired AI, neuroscience and neurotechnology research. We also have an **Embedded FPGA Hardware cluster and Design Resources** for accelerating novel bioinspired computing paradigms and hardware fault-tolerant and self-repairing systems (McDaid, Harkin).

3.3.2 Centres and their facilities

ISRC

The ISRC is located in a single 2000m² building with >50% dedicated research lab space along with a social dining area and 6 meeting rooms. Research labs/facilities include:

- **The Northern Ireland Functional Brain Mapping Facility** housing Ireland's only Magnetoencephalography (MEG) facility (whole head 306 channels Elekta Neuromag MEG TRIUX system and magnetic shielded room). It is one of 10 such facilities in the UK, one of only 170 active MEG labs worldwide, and the only housed within a computing and informatics unit globally (that we are aware of) - an indication of the interdisciplinary research drive and intent of the unit.
- **Brain-Computer Interface (BCI) Lab** is a dedicated facility for BCI research experiments and includes an EMF shielded and acoustic noise-insulated room with a 64 channel EEG system and multiple mobile EEG recording devices.
- **The Spatial Computing and Neurotechnology Innovation Hub** (officially opened by Princess Anne in January 2020) houses multiple technologies for electrophysiological monitoring including multiple mobile wearable EEG headsets 1x64 channel and 2x32 channels EEG devices, a functional near infrared spectroscopy (fNIRS) brain imaging headset, ECG, HRV, pulse oximeter, GSR, and technologies for spatial computing including text, voice, gesture, augmented reality/virtual reality, an advanced car/flight simulator and vibrotactile stimulation suits, ultrasonic haptic interfaces and technologies that enable walking in a virtual environments (virtual treadmills) as well as a state-of-the-art Smartglass façade to adapt the room for various experimental situations and public engagement activities.
- **The Cognitive Robotics Laboratory** is equipped with a wide range of advanced robotics platforms, such as the PR2 robot, Shadow Dexterous Hand, 2 SUMMIT XL robots, 4 SCITOS robots, Schunk manipulator arms, and 10 Pioneer P3-DX mobile robots with a powered floor

Unit-level environment template (REF5b)

(100m²). The laboratory has various vision systems and motion capture systems, permitting the capture of 2D/3D visual data, and a Vicon tracking system for sub-millimetre object tracking.

AIRC and PCRC

Both AIRC and PCRC are located in a single building with over 1000m² of dedicated research space along with a social dining area and two meeting rooms. Research labs/facilities include:

- **The Connected Health Living Laboratory (CH:LL)** enables assessment of usability and interaction in real-life environments and recording user behaviours with connected health solutions and includes a smart kitchen, smart living room and smart bedroom, supporting the investigation of assistive technologies and activity recognition. A set of 400 sensing nodes is available for deployment in a smart environment covering a footprint of over 600m².
- **The Maker Lab** supports the rapid prototyping of IoT endpoints and offers a large suite of pervasive sensing technologies, image and video modelling tools, computing and software resources.
- **BT Ireland Innovation Centre (BTIIC)** includes labs which house testbeds for smart networks and has access to a BTIIC research area with 15 desks in BT Belfast Riverside to enable co-location of PCRC/AIRC researchers, embedding BTIIC researchers and PhD researchers with BT engineering staff, enabling dissemination and down-streaming of their research results into BT systems and services.
- **A Hyperspectral Imaging Facility** is housed at the AIRC including state-of-the-art hyperspectral imaging equipment, as well as additional spectrometers to cover the full IR range. This supports the expansion of the research in spectral pattern recognition and its applications e.g., food authentication and more recently coronavirus detection.

As outlined in section 1 funding has been secured for new facilities and major expansion within the unit via the City Deals project and state-of-the-art facilities in the new Belfast Campus development to future-proof our growth plans. CS@Ulster has a very strong position in the UK, being involved in two separate City Deals, leading 2 innovation projects, and partnered with two others.

4 Collaboration and contribution to the research base, economy and society

4.1 Nature and scope of research collaborations

Networks and partnerships

CS@Ulster provides academic leadership at the national and international level, influencing and driving research agendas and strategy across a range of disciplines and domains. All of our main research themes are underpinned by funded collaborations with major academic and industrial research centres nationally and internationally.

Personal, funded research activities: examples include : research councils grants with Oxford (Wonglin), Strathclyde (Coyle), York (McDaid, Harkin), **and major national/international programmes such as US-Ireland tripartite grants** with NUI Galway and Kansas State University (McDaid, Harkin, Gardiner), University College Dublin and Columbia University (Wonglin), and Uni of California, Tyndall National Institute, University of Arizona, Columbia University, Uni of California, Berkeley, Trinity College Dublin and Dublin City University (Morrow, McClean, Scotney); **Royal Society Newton Mobility Grant** with University of Science and Technology Beijing, China (Chen, Nugent, Zhang), **Royal Society International Exchange Grant** with Tsinghua University, China (Wang, Scotney, Liu), **EPSRC Tier 2 National Infrastructure grant** with Queens Belfast (Coyle)

Through our collaborative EU-funded projects (discussed in Section 1 and 3), formal collaborations across Europe have been established. These collaborations are substantially interdisciplinary, involving engineers, neuroscientists, clinicians, therapists and healthcare professionals, and legal-ethical practitioners from medical, academia and industry. Examples include **PROGAI** (Coyle); **SenseCare** (Zheng); **MetaPlat** (Wang), **REMIND** (Nugent), **ACROSSING** (Nugent, Chen), **MENHIR** (Bond), **MIDAS** (Black); **Slandail** (Scotney); **SAVASA** (Wang); **VISUALISE** (Coleman), **DESIREE** (Wang), and **ASGARD** (Wang)

Fig. 7 shows the geographical spread of institutions/companies/hospital globally that have been involved as co-authors in the papers returned in this REF cycle (33 different countries). Overall, there was **189 different institutions** involved in outputs returned in REF2021 which is evidence of the extent of our collaborations. Further evidence of our collaborations is presented in sections 1.1.1 and 3.1.

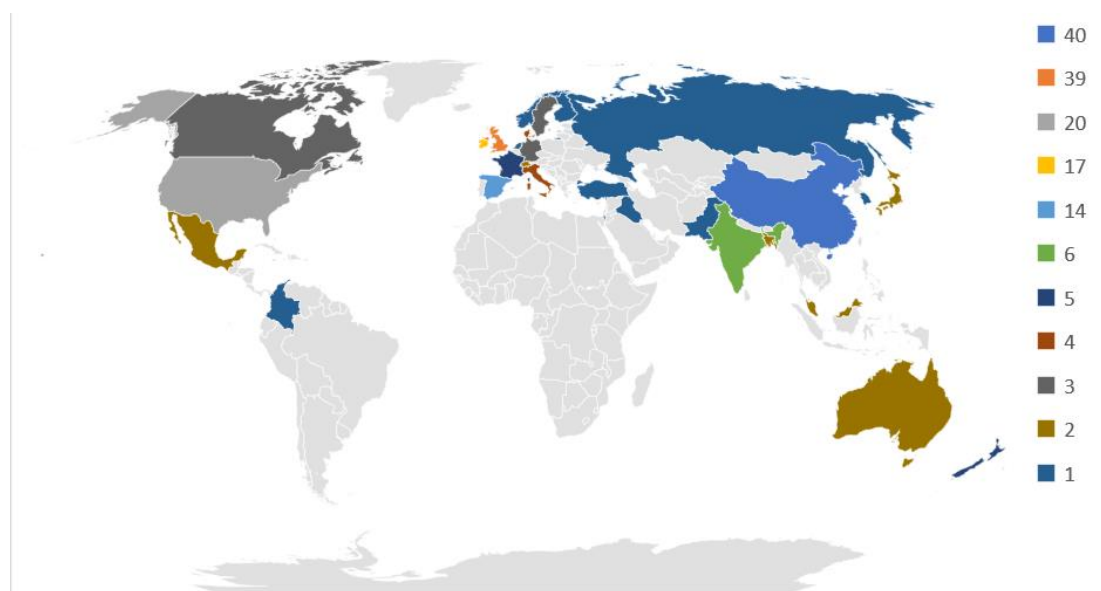


Fig.7. Number of institutions per country involved as co-authors in the outputs returned in REF2021 (Data taken from Scopus and excludes 4 recent outputs not yet available).

Visiting professor/scholar appointments

Visiting fellow/scientist/lecturer/professors appointment examples include Columbia University, USA (Kelso 2019); Honorary Professor of Teesside University (Kasabov, 2019); Robert Gordon University (Kasabov 2017) Scottish Information/Comp. Society, Distinguished Visiting Fellowship (Kasabov 2016); Shanghai Jiao-Tong University (Kasabov 2015 – 2020), Advisory Professor, Northeastern University in Shenyang, China (Coleman, 2018-2023); Shanxi University, China (Chen, 2018-present); Ecole Centrale de Lyon, France (Chen, 2014); Institute of Disaster Prevention, China (Bi, 2018-2021); Fujian Normal University, China (Wang, 2017-2022); Keio University, Japan (Scotney, 2017-); Lulea Technical University, Sweden (Nugent, 2011-present), Halmstad University, Sweden (Nugent, 2016-2018), Kyung Hee University, South Korea (Nugent, 2013-2014); Diakonhjemmet Sykehus AS, Norway, (Chen, 2013-2016), University of Deusto, Spain, (Chen, 2017-2020)

Industrial research collaborations

Other examples of industry collaborations include James Leckey Design (Cleland) (**associated ICS3**); Shearwater Systems Ltd, (Bai); I+ S.r.l, Italy (Nugent) (**associated with ICS4**); TNO, Netherlands (Galway); Sandvik Ltd (Hawe); BT (McClellan, Scotney, Nugent); Tech4Care, Italy; MiThings, Sweden (Charles); Qianhan Technologies (Chen); Cirdan Imaging, CareCall/Inspire Wellbeing, Verbal Arts (Mulvenna, Bond) (**associated with ICS5 and ICS6**); Guger technologies, Eksobionics, Seagate Technologies, Allstate NI, Sonae Retail, Dell, NVIDIA, NeuroCONCISE (Coyle) (**associated with ICS1 and ICS4**); BBC R&D (Wang) as well as NI Screen, BBC NI, Belfast City Council, Belfast Harbour, Causeway Enterprise Agency, Digital Catapult, Catalyst Inc., RTE, Games NI, Kainos, Invest NI, Techstart NI, Matrix and Tourism NI.

CS@Ulster lead/co-lead the majority of KTP projects at Ulster, with 23 new KTP projects being awarded in this REF cycle, with an overall value of over £3M.

Clinical collaboration

Partnering with over **70 hospitals/clinical units/health care providers CS@Ulster** research has involved direct research (basic science, clinical trials) with over 15 patient groups involving over **300 patients e.g., spinal injury, stroke, brain injury, motor neuron disease, mild cognitive impairment, Alzheimer's disease, children with disabilities, epilepsy, post-traumatic stress disorder among others.**

There are over 100 partnerships and international collaborations with other institutions globally (many evidenced by co-author publications, grant writing collaborations, co-awarded grants and research and innovation staff and student exchanges, co-organised events). Staff have hosted visits from over 50 faculty from around the world.

4.2 Key research users, beneficiaries and audiences**4.2.1 Awards**

Examples of recognition for academic leadership by external bodies with prestigious awards include:- 2018 INNS Ada Lovelace Award for Meritorious Service to the NN Community and the 2015 The AUT Medal for outstanding achievement (Kasabov); BIONICS project – Most innovative technology award, New Venture Competition, Carnegie Mellon (Coleman and Kerr); Prize Lectures in 2018: The B.F. Skinner Lecture, ABAI, San Diego, California; The Tourtellotte Lecture, Kalamazoo College, Michigan (Kelso); North-South Champion Coordinator in the Irish Champions of EU Research Forum & Awards (Black, Rankin for MIDAS project); Royal Irish Academy Charlemont Scholarship 2016 (Gardiner); Santandar Mobility Scholarship 2016 (Gardiner); Best overall game at the Fourth International Competition on Educational Games at the 10th ECGBL 2016), (Callaghan); Winner 7th International Competition on Educational Games, 13th ECGBL 2019, (Callaghan); IET Best startup 2018 and IET & E&T Innovation of Year Award 2018 (Coyle); outstanding contribution to the success and achievements of MOST/ESA Dragon programme 2012 to 2016 award (Bi); Invent competition finalist 2020 (Charles), Regional finalist and Regional winner of the seedcorn investor readiness competition 2018 (Condell and Coyle).

Example of best paper awards include : REV2014 (Callaghan); ICIET 2018 (Siddique); COGNITIVE 2016 (Vance); ICAR 2017 (Prasad); (HCI Track) at UCAMI 2016; WorldCIS-2015 (Hawe); Journal of Assistive Technologies, 2015; International Conference on Disability, Virtual Reality & Associated Technologies 2016 (Mulvenna); IEEE SmartWorld 2019 (Cruciani, Nugent, McCullagh, Chen); IMVIP2018 (Wang, Scotney); IMVIP2019 (Scotney, Zhang); IEEE HealthCom2017 and Global Health 2016 (Chen); FLINS 2018 (Wang, Lin, Hawe); IWAAL 2014, UCAMI 2015 and 2018 (Nugent, Rafferty); IMVIP 2018, IJCRS 2018 (Wang); Highly commended paper, Emerald Literati Awards. (Chaurasia, McClean, Scotney, Nugent); best paper award IMVIP 2016 (Gardiner); 2018 Neural Networks Journal Best paper, IEEE Intelligent Systems Best Paper 2020 (Kasabov); CERC 2020 (Wang, Santos, Zheng).

4.2.2 Keynote and Conferences

Our staff gave over **30 invited keynotes** at national and international events. Examples include:- IEEE ICES (McDaid); International Conference on Social Cognition in Humans and Robots, 2018; (Kelso); ICRAMTA2016; UK-China Robotics Forum, 2017 (Kerr); Infosecurity Europe, 2019 (Curran); ISSC2018, IDEAL2019; 8th Graz BCI Conference, 2019 (Coyle); International Conference on Information and Communication Technologies for Ageing Well and e-Health, 2020 (Mulvenna); IEEE Cyber Science and Technology Congress 2019 (Chen); 33rd International BCS Conference on HIC, 2020 (Bond); Third International Conference on Biological Information and Biomedical Engineering, 2019 (Zheng); 10th International Conference on Intelligent Systems and Knowledge Engineering, 2015 (Liu); International Conference in Data Science, 2019 (Wang); 2017 IEEE CPSCOM-2017, 2017 (Chen), ICOST2014, UCAMI2015, IEEE 19th International Workshop on Multimedia Signal Processing, 2017, The 7th Engineering, Science and Technology Conference, Panama, 2019, Global Conference on Artificial Intelligence and Applications, 2020 (Nugent), 32nd Human Computer Interaction Conference (Mulvenna); ICONIP 2017, IEEE SMC 2018, IJCNN 2019, IEEE Intelligent Systems 2020, Engineering Applications of Neural Networks (EANN) 2020, ACIIDS 2020, APSIPA 2020 (Kasabov).

Additionally staff have given **>100 invited talks at over 100** local, national and international conferences/ workshops and been involved in conference committees, organisation of special sessions, workshops and panels for many national and international conferences during this REF cycle and have served as **conference chair or co-chair** for over 20 conferences: e.g., IJCNN2018, NCEI2015 (Kasabov); IMVIP2014 (Coleman); MEGUK18 (Prasad); 37th European Cognitive Ergonomics Conference, 2019; (Bond, Maurice); IMVIP2018 (Scotney, Morrow); IEEE SmartWorld 2019; IEEEUIC2017, IEEEHealthCom2017, FTC2016, MoMM2014 (Chen); IEEEIoP 2019, ICT4AWE-2021, British HCI 2018 (Mulvenna); UCAMI2014, SUT4Coaching2016, SmarterAAL 2018, IEEE SCI2019, IWAH2020, (Nugent); CERC2020 (Wang, Zheng), ISKE2014, FLINS2018 (Liu).

Conference organisation: PCRC organised the 32nd BCS HCI Conference, 2018 (Bond) and IMPVIP, 2018 (Scotney) and AIRC organised IEEE BIBM 2014 (Zheng); FLINS 2018, ISKE 2018 (Liu) and ECCE2019 (Mulvenna) in Belfast. ISRC organised IMVIP2014 (Coleman), ISSC2017 (Curran) and MEGUK2018 (Prasad) and the 'Big Data for Health Policy Symposium' 2020 (Black) in Derry. Discovery Day for public engagement in research is held at the ISRC each year as part of the Northern Ireland Science Festival.

4.2.3 Editorship, peer review and board membership

Seven staff are members of the **EPSRC peer review college** (e.g., Coyle, Mulvenna, Sterritt, Hawe, Wonglin, Harkin, McGinnity) and many staff review for a range of national (e.g., MRC, BBSRC, Leverhulme Trust) and international research funding bodies (e.g., EU H2020, Danish Agency for Science and Higher Education; Canada Foundation for Innovation (CFI); Chilean National Science and Technology Commission, The Austrian Agency for the Promotion of Research (FFG), The Netherlands Organisation for Health Research and Development).

Staff are **guest editors/associate editors** of range of Journal titles, examples include, IEEE Trans on Neural Networks and Learning Systems (Coleman); IEEE Transaction on Games; Frontier in Neuroscience (Coyle); Journal of Neuroscience Methods (Wonglin); Human Movement

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Science; Motor Control; Chaos and Complexity Letters; Understanding Complex Systems (Kelso); Nature Scientific Reports; Journal of Behavioural Robotics (Siddique); IET Computers and Digital Techniques Journal (Harkin); Journal of Future Robot Life; The Journal of British Blockchain Association (JBBA); Cryptography; Computer Science and Electrical Engineering (MDPI); IET Networks; PLOS ONE (Cybersecurity & Blockchain); (Curran), J Technology and Health Care editorial board (McCullagh); Journal of Electrocardiology (Bond); Neural Networks, Information Sciences, Soft Computing Elsevier, Evolving Systems – Springer (Kasabov); IEEE Computer, IEEE Transaction on Human and Machine Systems, Journal of Ambient Intelligence and Humanized Computing, Personal and Ubiquitous Computing Journal, Pervasive and Mobile Computing, International Journal of Distributed Sensor Networks (Chen); IEEE Computer, MDPI Technologies, IEEE Journal of Biomedical and Health Informatics, Frontiers in Digital Health, International Journal of Computational Intelligence Systems, BMC Medical Informatics and Decision Making (Nugent); Communications in Statistics–Theory and Methods (McClellan); Journal of Informatics (Shuai, Nugent); International Journal of Data Mining, International Journal of Computers in Healthcare, BMC bioinformatics, International Journal of e-Healthcare Information Systems (Zheng); IEEE Transactions on Computational Biology and Bioinformatics, International Journal of Machine Learning and Cybernetics (Wang); Journal of Fuzzy Mathematics, International Journal of Computational Intelligence Systems, Information Science Journal, Journal of Ambient Intelligence and Humanized Computing (Jun); The Journal of Engineering (IET), Interacting with Computers, Behaviour & Information Technology (Mulvenna); ACM Transactions on Autonomous and Adaptive Systems (TAAS) (Sterritt); Journal of Wireless Communications and Mobile Computing Journal (Cleland); Behaviour in Information Technology Journal (Bond); BMC bioinformatics (Zheng); IEEE Transactions on Computational Biology and Bioinformatics (Wang); Information Science Journal (Liu); IEEE Transactions on Cybernetics, The Computer Journal, IET Computer Vision on Video Analytics (Wang).

Staff have authored monographs, e.g., two published by Springer, 2019 (Chen, Nugent) and (Kasabov) and **guest edited a range of special issues/edited books**, including Frontiers In Neuroscience; Progress in Brain Research Edited book, Elsevier (2016) (Coyle); The Springer Handbook of Bio- and Neuroinformatics, Springer (2014) (Kasabov); Cyber-enabled Intelligence, CRC Press, Taylor & Francis (2019) (Chen); Smart Assisted Living: Toward An Open Smart-Home Infrastructure, Springer (2020) (Chen, Nugent); Emerging Trends and Advanced Technologies for Computational Intelligence, book series: Studies in Computational Intelligence, Springer (2016) (Chen).

UoA11 staff also serve as member or chairs of or have provided advise to various **advisory panels/committees**, including: KTN Neurotechnology Innovation Network advisory board member, IEEE Brain Initiative Core Team, IEEE Brain Technical Community Steering Committee; IEEE Computational Intelligence Society UKRI Chapter (chair), Member of the UK Traumatic Brain Injury Network (Coyle); ECR rep for Demon Network; C-TRIC COVID-19 Task Force; Ulster rep on the NI Department of Health Covid-19 Modelling Group (Bucholc), Chair, British Neuroscience Association (BNA) Chapter for Northern Ireland (Wonglin); President of the Irish Pattern Recognition and Machine Vision Society (Coleman), Chair Library Committee of the London Mathematical Society; Chair of Council of the British Soc. for the History of Mathematics (McCartney); Member for Professional Accreditation for the Operational Research Society (McClellan); Member of IEEE CIS Smart World Technical Committee (Chen); Member of the EPSRC Image Guided Therapies UK Network+; Member of ESC Working Group on e-Cardiology; Member of PDF-ECG Working Group; Directing Board Member for International Society for Computerised Electrocardiology; Member of Working Group for IEEE 7003 Standard on Algorithmic Bias; (Bond); Committee member of the International Scientists for the China Seismo-Electromagnetic Satellite Mission (CSES) (Bi); Engineers Ireland - Accreditation Panel (Davies); IET Policy Group for Northern Ireland (EPGNI); Member of Belfast Turing Lecture Organising Committee; Deputy Chair of NI Science Festival; Chair of Belfast Turing Lecture Organising Committee (Wallace); Global Future Council on Neurotechnologies and Brain Science for the World Economic Forum; President of the International S.T.E.P.S (Science, Technology, Economics & Politics for Society). Foundation & Chairman of The Olympiads of the Mind (Kelso); IEEE public visibility committee, British Blockchain Association Advisory Board Member;

Unit-level environment template (REF5b)

WebRoots Democracy Cratos project Advisory Group Member; Northern Ireland Civil Service Cyber Leadership Board, UK Cyber Security Council (Curran); Council Board Member, European Society for Engineering and Medicine (Donnelly); IEEE SMC Society Ireland Chapter chair (Wang) and Senate of the Indian Institute of Information Technology, Pune (Prasad).

4.2.4 Fellowship and membership

Staff are affiliated with/have membership of a range of learned societies.

Example of prestigious fellowships/position held by staff include: Fellowship of International Academy of Physical Sciences (IAPS) (Prasad); Fellow of The Society of Experimental Psychologists (SEP); Honorary Member of the Royal Irish Academy (Kelso); Fellow of the British Blockchain Association (Curran); Fellow of the IET (Chen, McGinnity, Maguire); Chartered Fellow of the British Computer Society (BCS) (Mulvenna); Doctor Honoris Causa, Obuda University, Fellow of the INNS College of Fellows, President of the Asia-Pacific Neural Network Society (APNNS), 2019 (Kasabov); Royal Academy of Engineering/The Leverhulme Trust Senior Research Fellow, 2013; Royal Academy of Engineering Enterprise Fellow, 2015; UKRI Turing AI Fellow, 2021-2025 (Coyle).