Improving recognition of team science contributions in biomedical research careers

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The Academy *of* Medical Sciences

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Executive summary

Team science – output-focused research involving two or more research groups – is becoming more common as researchers seek to solve global challenges to realise economic and societal benefits. Sequencing the human genome, major clinical trials and longitudinal cohort studies, such as UK Biobank, have involved large teams working together to solve complex problems. Smaller-scale team science is also on the rise, driven by groups collaborating with others who provide expertise in complementary areas such as imaging and statistics.

Working in this way can be hugely beneficial for the scientific endeavour but at what cost for the individuals undertaking the work? The Academy of Medical Sciences (the Academy) and others have explored whether biomedical researchers are being encouraged, supported and rewarded for participating in team-based approaches. Our findings indicate that academic reward and recognition systems have failed to match the growth of team working; academia is rooted in a tradition of individual and small-team scholarship where the emphasis is on leadership and independence.

The Academy established a Working Group to investigate the impact of team science upon individual biomedical researchers (particularly earlier career researchers), with a focus on the UK. In developing the recommendations, the Working Group engaged extensively with a wide number of researchers, funders, employers and publishers. Although we are aware that others have already highlighted the impacts of team science, to our knowledge, this is the first policy report to investigate this topical issue from a career perspective.

A key finding was that the likely lack of recognition for one's contributions is the main challenge for researchers participating in team science. It appeared that career development issues were consistent, regardless of the size of teams. Therefore, academic recognition must embrace a fundamental change: it must provide improved information about the contributions of individual team members and use and value it in assessment.

The lack of structured information on the contribution of individuals to research outputs and grants renders the allocation of credit, and accountability for the roles and activities critical to team science, impossible. When evaluating researchers' track records, the focus is currently on their first and last author publications and whether they have been 'lead' principal investigator (PI) on grants, both of which are relatively difficult for individuals to secure when working in teams.

Systems that provide structured contribution information for research outputs and grants must be developed, phased in and evolved. They must be: of use to researchers, employers and funders; available when the output is first produced; and agreed upon by all participant researchers. All stakeholders should strive toward interoperable research information systems where structured contribution information can be aggregated using individual researchers' identifiers i.e. ORCIDs (Open Researcher and Contributor ID). To drive provision of this information, as well as the necessary culture change, funders and employers must place contribution information at the heart of their decision-making. Researchers should be made aware of the criteria being used to assess career development, and the processes for appraising their contributions at all stages.

While recognition systems are at the heart of implementing change, the Working Group also recommends changes to funding, researcher behaviour, training, and career development of skills specialists:

- **Funding opportunities for team science must be sufficiently flexible and generous to facilitate excellent research involving adequate career development opportunities.** Whilst funders highlighted the flexibility of their schemes for team science, researchers and employers widely perceived that awards and contracts for staff do not reflect the longer timescales required to build and co-ordinate teams; and additional resourcing, such as project managers and face-to-face meetings for effective team working, is needed. To ensure that funding opportunities facilitate but do not prioritise team science, funders should review the balance, flexibility, length and magnitude of funding. Funders should use this review to engage with the research community to improve and enhance their support for team science.
- **Researcher 'best practice' in delivering successful and equitably credited team science needs to be identified, celebrated, shared and enacted.** All researchers should agree milestones, credit and responsibilities throughout and log contributions as projects progress. Team leaders have an important additional role in instilling the right culture and behaviours. Funders and employers should develop and implement specific mentoring schemes aimed at supporting researchers involved both in assessing and conducting team science to enhance these skills.
- **Focused and appropriate training in team skills, and opportunities for exposure to team science, must be provided to all researchers.** Key skills such as networking, leadership, management, managing bias, assertiveness, and resolving conflict are critical for ensuring that team science projects are successful and beneficial to those participating. These skills need to be improved amongst academic researchers through employers reviewing and drawing on existing best practice to develop and provide nationally recognised training in team skills for researchers at all career stages; and funders evaluating the team leadership track record of intended leaders on team science proposals. Funders, employers and researchers should work together to develop appropriate forms of evidence of team skills.
- **'Skills specialists' need a clear, well-supported career path, adequate resourcing of their roles, and provision of relevant career development opportunities.** Successful team science relies on the work of researchers outside of the classical 'PI' career path: PI-track individuals cannot embody all the core specialist capabilities needed. 'Skills specialists' often participate in multiple team science projects, and are present at most universities and research institutes, staffing the core facilities and providing important expertise. Employers should actively manage these specialist staff to develop their careers and support them to deliver team science. Researchers should fully acknowledge skills specialists in research outputs, for example as authors and/or contributors on papers.

Team science is not only likely to become increasingly common but increasingly necessary, and therefore it needs to be an attractive option for researchers. This report calls for a co-ordinated effort from all stakeholders to address the recommendations and ensure that those who participate in team science are well recognised, rewarded, trained and supported.

Recommendations

Key

Stakeholders

- Employers
- Researchers
- Publishers
- Funders

Themes

- Contribution Information Framework
- Contribution Portfolio
- Digital Identifiers
- Funding
- Interoperability
- Leadership
- Researcher Responsibility
- Team Skills Training

Recognition

Recommendation 1

All research outputs and grants should include open, transparent, standardised and structured contribution information.

- *Publishers* should work with relevant initiatives, such as Project CRediT, and the research community to develop, pilot and evolve a standardised contribution information framework for publications.
- To ensure that the information captured is fit for their respective purposes, employers, funders and researchers need to engage with *publishers* in developing the framework.
- For team science grants, *funders* should phase out any requirement for a 'lead' or 'principal' investigator, and list all applicants as 'co-applicants'. *Funders* need to develop and publish clear criteria for co-applicant status. In addition, we recognise that *funders* may require one co-applicant to be identified as the 'administrative lead'.
- *Researchers* should be required to provide a statement describing the contribution of each co-applicant to the grant.

Key Stakeholders

Key Themes

Recommendation 2

The most effective way of providing contribution information will be an open and transparent research information infrastructure which links all research inputs and outputs to individual contributors.

- *Researchers* should obtain an ORCID ID and link it to all their research activities.
- *Publishers* should ensure that publications include ORCID IDs for any associated inputs and outputs.
- As publishers do for publications, *data and software repositories* should also link to ORCID.
- Likewise, *funders* should develop and use publicly-accessible grant information databases, wherein each record is linked to ORCID.

Key Stakeholders

Key Themes

Recommendation 3

Information infrastructure must minimise researchers' overall administrative burden and should be interoperable.

- *Funders* should ensure that their application and grant reporting systems are interoperable with those of *employers*.
- *Employers* must ensure that their institutional research information systems are interoperable with publicly available databases, such as ORCID.

Key Stakeholders

Key Themes

Recommendation 4

The use of 'key' positions on publications and grants as the primary indicator of research performance, leadership and independence in team science projects should be replaced by transparent, fair processes.

- *Employers* should use individuals' contribution portfolios when appraising them for recruitment and promotion.
- *Funders* should use individuals' contribution portfolios when appraising them as part of a funding application.
- Both *funders* and *employers* should update their criteria for career development at all stages. This information should be available publicly and communicated clearly to all researchers.
- With the phasing in of contribution information on publications, *researchers* and *publishers* should engage in active debate about phasing out author listing traditions for team science projects.

Key Stakeholders

Key Themes

Key

Stakeholders: Employers, Researchers, Publishers, Funders

Themes: Contribution Information Framework, Contribution Portfolio, Digital Identifiers, Funding, Interoperability, Leadership, Researcher Responsibility, Team Skills Training

Funding

Recommendation 5

Team science funding should provide the length, breadth and magnitude of support required by recognising the longer timescales often needed to achieve outputs and additional costs associated with effective team working.

- *Funders* should regularly review the balance, flexibility, length and magnitude of their funding for team science projects, and publish the outcomes.
- *Funders* should use the published outcomes as the basis for consultation with the research community on ways to improve team science funding.

Key Stakeholders: Funders

Key Themes: Funding

Recommendation 6

Team science grant proposals need to be appraised holistically, as well as from the perspective of the relevant disciplines.

- *Funders* should review policies and processes for obtaining appropriate peer review and appraisal of team science grant applications, and make changes where necessary.
- *Funders* should induct and train peer and panel reviewers, as well as grant managers, to meet this challenge.

Key Stakeholders: Funders

Key Themes: Funding

Recommendation 7

The value of project leadership should be evaluated when appraising team science grant proposals.

- *Funders* should evaluate the leadership track record of designated leaders on team science grant proposals.
- *Funders* should work with employers and appropriate expert bodies to develop clear, publicly-available guidance on relevant forms of evidence that could be used for this purpose.

Key Stakeholders: Employers, Funders

Key Themes: Funding, Researcher Responsibility, Leadership

Researcher behaviour

Recommendation 8

Researchers should drive change through their crucial roles as team members, peer reviewers and participants on recruitment, promotion and funding panels.

- As team members, *researchers* should:
  - Ensure that credit is allocated fairly and transparently.
  - Define clear areas of responsibility for all individuals involved at the outset in team science projects, and review these throughout.
  - Proactively seek feedback and gather evidence to demonstrate their leadership track record, based on funder guidance (Recommendation 7).
  - Obtain training in team skills (Recommendation 9).

Key Stakeholders

Key Themes

Training

Recommendation 9

Focused and appropriate training in team skills should be provided.

- *Employers* should develop and provide training in team skills for researchers at all career stages. This training should be nationally recognised and cover dimensions such as leadership, management, team working, conflict resolution and unconscious bias.
- *Funders* should make career development a deliverable of grants, capturing and presenting next destinations of researchers in publicly-accessible grant reports.
- *Researchers* should be required to outline plans for governance, career development and training provision in grant applications.
- *Employers* and *funders* should train peer reviewers and panel members in how to evaluate contribution portfolios when making employment or funding decisions regarding other researchers.

Key Stakeholders

Key Themes

Skills specialists

Recommendation 10

Clear career paths and development opportunities should be provided for researchers outside of the 'PI track' who play key roles in (and provide key competencies to) team science, such as skills specialists.

- *Employers* should actively manage skills specialists to develop their careers and support them in helping to deliver team science.
- *Researchers* should acknowledge skills specialists appropriately in research outputs, for example as authors and/or contributors on papers.

Key Stakeholders

Glossary of terms and abbreviations

This glossary is intended to assist readers with the terminology and abbreviations used in this report; it is not presented as a definitive list of terms.[1]

AACR: American Association for Cancer Research

API: application programming interface

BBSRC: Biotechnology and Biological Sciences Research Council

CASRAI: Consortia Advancing Standards in Research Administration Information

CERN: European Organization for Nuclear Research

CIHR: Canadian Institutes of Health Research

Co-I: co-investigator; an individual who assists the principal investigator in the management and leadership of a research project.

Contribution information: structured information on the contribution of individuals to grants and research outputs, such as publications and data-sets.

CRIS: current research information system; a database used to store information about research conducted at an institution.

DOI: digital object identifier; a serial code used to uniquely identify objects, particularly used for electronic documents such as journal articles.

DORA: San Francisco Declaration on Research Assessment

DTP: Doctoral Training Partnership

EAGDA: Expert Advisory Group on Data Access

ECRs: early career researchers; researchers who are at a career stage post-PhD but before attaining an established independent academic position. Examples include postdoctoral and career development fellows, and newly appointed lecturers.

EU: European Union

GEO: Gene Expression Omnibus

HEFCE: Higher Education Funding Council for England

HEI: higher education institution; any provider which is one or more of the following: a UK university; a higher education corporation; a designated institution.

HEP: high energy physics

HFSP: Human Frontier Science Program

ICMJE: International Committee of Medical Journal Editors

MRC: Medical Research Council

NHS: National Health Service

NIHR: National Institute for Health Research

NSERC: Natural Sciences and Engineering Research Council of Canada

ORCID: Open Researcher and Contributor ID; an open, non-profit, community-driven effort to create and maintain a registry of unique researcher identifiers and a transparent method of linking research activities and outputs to these identifiers.

PI: principal investigator; the lead researcher for a particular project, such as a laboratory study or a clinical trial.

PLOS: Public Library of Science

Project CRediT: contributor roles taxonomy; a 14 'contribution types' taxonomy designed to represent the range of contributions to scientific publication outputs to allow researchers to gain credit for their contributions.

PURE: a university publication and research information management system.

RCUK: Research Councils UK

R&D: Research and Development

REF: Research Excellence Framework; the current system for assessing the quality of research in UK higher education institutions.

Skills specialists: individuals outside of the classical PI career path, who provide expertise in areas such as equipment operation and project management. These individuals staff core facilities such as flow cytometry, mass spectrometry, genomics, imaging, electron microscopy or provide statistical analysis expertise at most universities.

TRPs: Translational Research Partnerships

UCL: University College London

WTCCC: Wellcome Trust Case Control Consortium

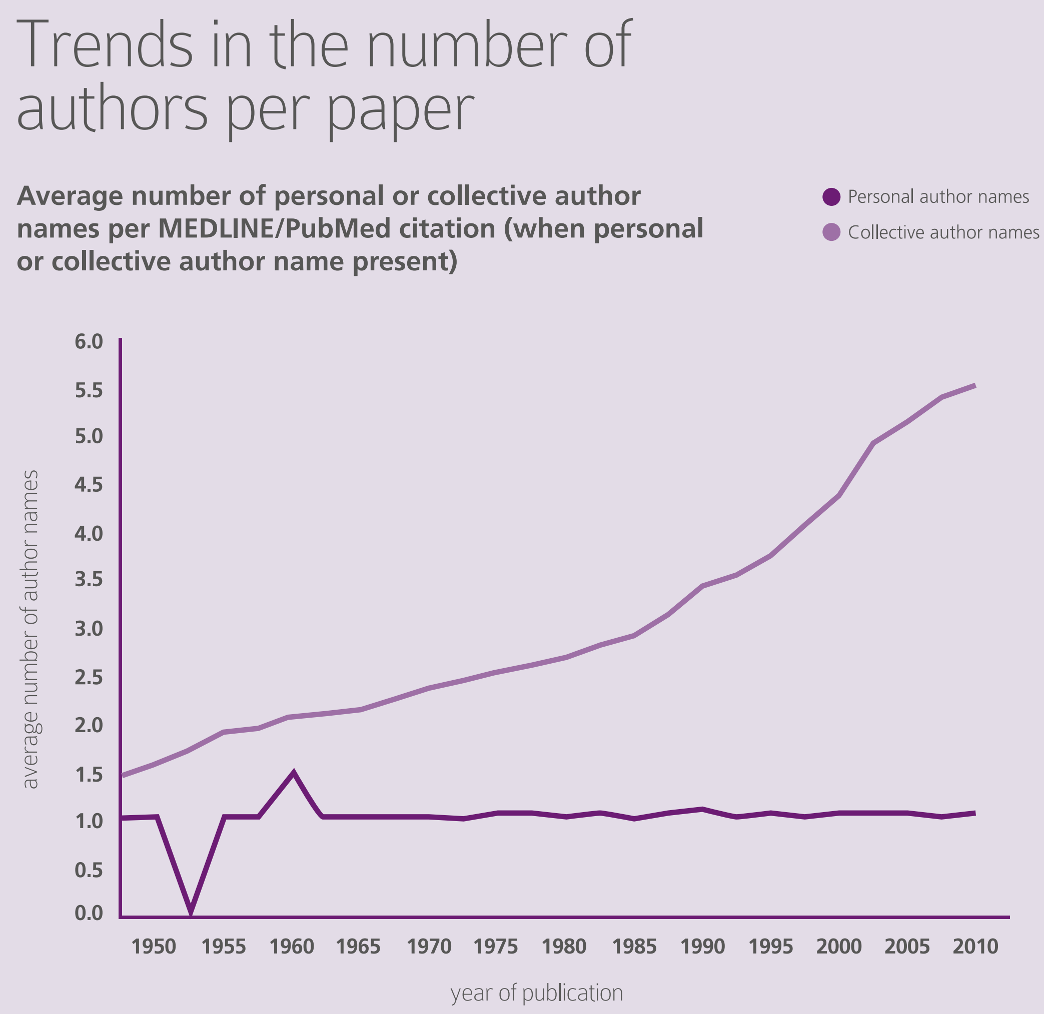
1. Terms are drawn from sources including Wikipedia https://en.wikipedia.org/wiki/Main_Page, https://je-s.rcuk.ac.uk/handbook/pages/GuidanceonCompletingaStandardG/Co_Investigators.htm, http://orcid.org/about/what-is-orcid; http://www.hefce.ac.uk/glossary/

1. Introduction

1.1 Team science is increasingly common

We are in an era of increased collaboration, with research in many areas of science requiring teams from different disciplines, institutions, countries and sectors (e.g. academia, NHS, healthcare, industry) to work together. This increase is demonstrated by the rising average number of authors on papers over time (Figure 1), which is expected to continue, alongside an increasing proportion of papers involving multiple disciplines and international collaborations.[2,3,4,5] There has also been a rise in the number and percentage of publications in biomedical and clinical journals in which two or more co-authors claim first authorship (Figure 2).[6] Whilst team science is often typified by well-known examples of very large projects with author lists in the thousands, such as those being conducted at CERN, the EU Graphene initiative and the human genome project are examples of how team science can also be conducted at smaller scales.[7,8,9,10,11,12,13]

Figure 1: Trends in the number of authors per paper, based on PubMed records of all articles published 1950–2014.



Courtesy US National Library of Medicine (NLM)

Over this period, the average number of authors has increased from 1–2 to 5–6.[14]

Figure 2. Trends of co-first author manuscripts in biomedical journals (A) and clinical journals (B)

The figures show a rise in the percentage of publications in biomedical and clinical journals in which two or more co-authors claim first authorship.[15]

1.2 Reasons for the increase

While technological developments in digital communication have made team science research across institutions and countries more attractive and feasible, the drivers for the increase arise from researchers, funders, publishers and employers.

Resourcing biomedical research is now often driven by a number of factors, including: necessity (e.g. when a range of skills or resources are required that go beyond those found in a single research group led by a PI); a desire to be involved in research that is more impactful, novel and exciting; a desire to acquire new skills. Linking clinical and other researchers is a particularly sought-after goal for many funding agencies.

The trend for larger projects can be driven by a desire to increase the volume of data collected and improve the statistical power, and often require international collaborations, such as whole genome-wide association and population studies, and clinical trials.

Research funders, at national and international levels, encourage collaborations in order to enable complex projects such as clinical trials, translational studies, and projects addressing grand global challenges to be undertaken, and are increasingly prioritising such projects (see Boxes 1 and 2 for examples of the impacts arising from team science and a range of team science projects).

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Our findings indicate that academic reward and recognition systems have failed to match the growth of team working.

Box 1. Examples of the impacts of team science

The promise of team science is that of increased novelty and chance of impact, and many funders support it for these reasons. There is some indication that international collaboration has a strong, positive influence on both journal placement and citation performance in most disciplines.[16] The REF2014 exercise highlighted the impact of team science: 87% of the 6,975 impact case studies submitted were multidisciplinary. Below, we provide some of the many individual examples suggested to us of the impact of team science, from a range of projects:

- An international team of researchers, cavers and explorers recently discovered multiple specimens of *Homo naledi*, a previously unknown species of extinct hominin, in a South African cave.[17]
- Researchers at the Lifelong Health and Wellbeing Centre for Cognitive Ageing and Cognitive Epidemiology and the Edinburgh Delirium Research Group, at the University of Edinburgh, developed a quick and simple method for diagnosing delirium. In collaboration with a company called Eagle Designs, they designed 'Delbox', the first computerised testing device used to detect delirium using simple visual tests.[18]
- Researchers from multiple institutes and universities developed computational methods that were applied to the design of control programmes for *C. difficile* in hospital wards. This was rolled out in 2008 in the NHS Lothian regions, reducing incidence by around 65%, saving an estimated £3.5 million per annum in treatment and other costs, reducing mortality and improving patient outcomes.[19]
- Researchers at the University of Cambridge, in collaboration with the Wellcome Trust Sanger Institute, identified a new strain of methicillin-resistant *Staphylococcus aureus* (MRSA) in livestock. As a consequence of these findings, commercial tests and testing protocols have been developed to detect the new MRSA variant, and are now used widely by MRSA reference laboratories throughout Europe.[20]
- The Wellcome Trust Case Control Consortium (WTCCC) is a collection of 50 research groups from across the UK conducting large-scale genome-wide association studies in different diseases to identify common genetic variations for each condition. [21] The WTCCC has identified many novel gene variants that affect susceptibility to disease.
- An interdisciplinary collaboration at the University of Dundee examined the link between metformin and cancer, and reported in 2005 that people with diabetes taking metformin had a reduced incidence of cancer. The impact has been worldwide clinical trials testing the benefit of metformin for cancer treatment, and the development of therapeutics by pharmaceutical companies targeting this pathway.[22]
- Interdisciplinary work by microbiologists and materials science collaborators has led to the development of novel environmentally friendly coatings for anti-corrosion and the development of a platform technology that includes an antimicrobial coating which is currently under investigation for use on orthopaedic prostheses.[23]
- Research involving numerous studies with obese human volunteers led to the development of the Fuller Longer range of products which are intended to support weight loss or weight maintenance diets. An interaction with Marks and Spencer (M&S) took the research findings through to the marketplace. Figures for sales in January 2012 indicate 1.5 million meals were sold in a week.[24]

1.3 The career challenges presented by team science

There has been increasing discussion of the rise and impact of multidisciplinary work, and the need to facilitate it and encourage more effective team-based science.[25,26,27,28] The 'science of team science' is growing, as indicated at a recent conference in the USA.[29]

The Academy held a roundtable discussion in 2012 to debate issues emerging from increases in team science. Career development and recognition emerged as prominent issues and are related to concerns about the impact of growing author numbers on publications. A recent article, focusing on interdisciplinary research, recognised that it *'is harder to fund, do, review and publish – and those who attempt it struggle for recognition and advancement'*.[30,31,32] Undertaking team science brings challenges that arise from the way that research activity is assessed and supported, thus presenting barriers to the career development of those involved. Critically, whilst team science is often recognised as important, there is little evidence that individuals' contributions will be valued in career-relevant decision-making, which is particularly concerning for PhD students and early career researchers (ECRs). We define ECRs as researchers at a career stage post-PhD but before attaining an established independent academic position, such as postdoctoral and career development fellows, and newly appointed lecturers. A recent report from the European Science Foundation surveyed 500 postdoctoral researchers from multiple disciplines and found that nearly 60% of them are engaged in interdisciplinary work.[33]

Although team-based research appears to be increasing, career structures are lagging behind the pace of change.

1.4 Definitions and scope

In 2013, initiated by our Academic Careers Committee, the Academy started this project, aimed at enabling academic researchers to gain maximum benefit and appropriate reward and recognition from their participation in team science. We investigated the current opportunities and challenges for researchers, particularly ECRs, participating in team science and formulated recommendations to address the challenges.

The project does not aim to promote team science as a more desirable approach than single investigator/single group approaches. Whilst we recognise the increasing prominence of team approaches and evidence of their impact, single group approaches continue to make valuable contributions to biomedical research. In an ideal world, researchers should be able to decide whether team science is the best way to achieve results, unburdened by concerns about negative effects on their career development prospects.

In this report, we use the term 'team science' to mean any team-based research involving two or more research groups (even if they are all within the same department and/or institution, or all of the same discipline) that aims to produce an academic publication or other research output. Therefore, this definition excludes research that only involves individuals from a single academic group led by a single PI (Box 2).

Although this report focuses on UK biomedical academia, the project has been informed by looking to different countries and research sectors (e.g. industry and the NHS).

The project was led by an expert Working Group, which gathered a wide range of evidence and interacted with a wide range of key stakeholders, including: individual researchers, organisations representing researchers, research employers, research publishers and research funders – including those undertaking research assessment exercises.

Box 2. Types of teams and our definition of team science

A team is any group of people who come together to undertake research that they could not achieve in isolation. Teams come in many different forms and sizes. Our project used a definition that is agnostic to the type of team: any work involving individuals from more than one PI-led group. We recognise that those within similar disciplines interacting within the same institution may often not consider this to be team science. However, it is important that small, as well as large, teams are recognised as team science by researchers, employers and funders. We also expect many of the findings of this report to have a positive impact on team science within labs/institutions.

Teams can comprise individuals that differ in any number of the following characteristics: skills speciality, discipline, employer, or country. Team science can take the form of 'challenge-led' projects, which are typically instigated and run via top-down schemes, or of 'discovery-led' projects, which arise through bottom-up initiatives. We note that the terms 'interdisciplinary' and 'multidisciplinary' are often used interchangeably. Multidisciplinary research is taken to mean research that involves more than a single discipline in which each discipline makes a separate contribution. Interdisciplinary research is when ideas and methods between two disciplines are integrated and synthesised, often leading to a new research field or discipline.[34] As the following examples indicate, team science may occur within a single discipline or across disciplinary boundaries (interdisciplinary or multidisciplinary) and can involve collaborations either within one institution or among multiple organisations.

Same faculty, same institution:

- This type of team science largely consists of collaborations between laboratories within the same university or organisation – for example, between groups that use the same technique or that share facilities. Although these interactions are usually smaller-scale than large multi-institute projects or cross-disciplinary research initiatives, they are nevertheless an important manifestation of team science and should be recognised as such.
- The Wellcome Trust Sanger Institute's **Copy Number Variation Project** involves team efforts to screen healthy individuals for genetic mutations that may contribute to disease.

Multiple faculties/disciplines, same institution:

- The **British Heart Foundation Centre of Research Excellence** at King's College London promotes a collaborative, multidisciplinary environment to catalyse innovative research by combining the expertise of cardiovascular biomedicine, biophysics and biomedical engineering.
- The **Usher Institute of Population Health Sciences and Informatics** at the University of Edinburgh brings together expertise in disciplines ranging from informatics to ethics to geography, in order to advance population health research.

Same faculty/discipline, multiple institutions:

- **CERN** is a European centre for research on particle physics involving 21 member states, which all contribute to operating costs and participate in decision-making about the organisation.
- The **Pan-Cancer Analysis of Whole Genomes project**, a collaboration between the Cancer Genome Atlas and the International Cancer Genome Consortium, conducts co-ordinated analysis of cancer genomes.

Multiple faculties/disciplines, multiple institutions:

- The Biotechnology and Biological Sciences Research Council's **Networks in Industrial Biotechnology and Bioenergy** promote translation of research into benefits by supporting interactions of academia and industry.
- The **Innovative Medicines Initiative** facilitates collaboration among European universities, industry, regulators and patients to speed development of innovative treatments.

1.5 The timeliness of this project

The UK academic sector is now in the post-2014 Research Excellence Framework (REF2014) period of reflection, and 'impact' and team science will be shaping the future attitudes of employers and funders towards the next research evaluation exercise. The report of REF2014's Main Panel A, covering the full range of bioscience, biomedical and clinical medicine, stated that the assessment exercise *'illustrates, in particular by way of the submitted impact cases, the increasing power of the contribution that multidisciplinary teams make to translational research and innovation',* highlighting the importance of teams that combine multiple disciplinary backgrounds and skill sets. The report also stated that *'successful translation to impact requires, for example, the integration of medicine and biology, or engineering, physics and mathematics to conceive new, more sophisticated medical devices and treatment regimes'.*[35] Concerns about addressing barriers to interdisciplinary research were also raised in the conclusions of a recent report undertaken as part of the REF2014 evaluation.[36]

There is an increasing appetite to encourage interdisciplinary research and investigate the barriers to conducting it.[37,38,39,40] The challenges include improving the mobility of researchers between academia and industry and enhancing the skills and experience of academics through emulating the team structures and approaches used in industry.

1.6 Structure of the report

Chapter 2 outlines the terms of reference and the process of undertaking the project, indicating the considerable engagement that has been achieved. In Chapter 3 we outline the vision, opportunities and challenges, and recommendations arising from the project. We also describe ways to achieve the Working Group's vision by focusing on the key career development challenges faced by researchers participating in team science: recognition; funding; researcher practice and behaviour; training and exposure; and supporting staff. The conclusions of the report are drawn together in Chapter 4. A full list of recommendations and lists of individuals and organisations involved and engaged are provided as annexes.

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2. Method of working

2.1 Terms of reference

The Working Group members (see Annex I) adopted the following aims for the project:

- To explore and define the benefits and challenges to individual biomedical researchers arising from their participation in team science.
- To explore and define the barriers to ensuring appropriate reward and recognition for individual biomedical researchers participating in team science (particularly early career researchers).
- To make recommendations that address these challenges and barriers. The recommendations will aim to catalyse the development and establishment of processes to generate, and use evidence of, contributions to team science projects to support individual career progression.
- To influence the behaviour of researchers themselves, as well as the policy and practice of publishers, employers and funders – including those undertaking research assessment exercises (e.g. the REF).

2.2 Evidence gathering and engagement

A list of those who contributed to the project is available at Annex II.

Written evidence

The Working Group launched the project on 15 September 2014, collecting written evidence for eight weeks until 7 November 2014. A wide range of organisations – employers, funders, publishers and others, mostly from the UK, but also from the rest of Europe, North America and Australasia– were invited to submit evidence to the project, as were individual researchers. The Working Group received over 20 organisational and 20 individual responses.

An image competition was run alongside the call for written evidence. Researchers were asked to send in 'creative images representing their research team'. The winning image, which can be found on our website, was from the Modernising Medical Microbiology group at the University of Oxford.[41]

Local evidence gathering

Researchers at all career stages were engaged via a series of local sessions hosted by members of the Working Group. The sessions were held in: Bristol, Cambridge, Leeds, Liverpool, Dundee and Edinburgh. Collectively, they engaged more than 70 researchers at different career stages: from PhD students to professors.

The Working Group developed a guidance document used by the session chairs who then provided detailed written reports of the discussions.

Discussion of team science was also included at Academy career development events held in Edinburgh (September 2014) and Newcastle (February 2015).

Discussion sessions

In February 2015, the Working Group held roundtable discussions focused on three areas: employment, funding and publishing. Each roundtable comprised a small group of key individuals from the sector in discussion with the Working Group, and was held under the Chatham House Rule. These sessions allowed the Working Group to deepen their understanding of the issues and start to outline emerging conclusions and policy recommendations for the project.

Researcher workshop

A workshop was held with around 30 researchers in May 2015 to discuss the project's findings so far, and to inform the further development of conclusions and recommendations. Researchers were drawn from a range of career stages (from PhD students to professors) and disciplines, including clinically qualified researchers.

Mixed-stakeholder workshop

In September 2015, a workshop was held to discuss the challenges and potential solutions identified by the project, with a mixed group of around 40 key stakeholders representing funders, employers, publishers and the researcher community.

The Working Group and the Secretariat also engaged with several other projects through participation at workshops (see Annex II for details).

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3. Vision, opportunities, challenges and recommendations

3.1 Vision

Developing and maintaining an engaged and effective body of researchers is vital for science. As well as being driven by scientific curiosity and the stimulation provided by uncovering new knowledge, researchers want the same assurances about their performance as other career types, i.e. to be recognised for their achievements and rewarded appropriately. Here, we set out our vision, detailing the requirements that we believe will be necessary to improve the current system in the face of the many opportunities and challenges of team science.

While recognising that a variety of organisations are important to the outcomes, that research is a global enterprise and that the pace at which sectors, institutions and individuals can and will implement change differs, we have nonetheless proposed a timeline for implementation (Table 1). The Academy plans to convene a follow-up meeting two years after the launch of this report to assess progress.

Our vision is to improve career development prospects for all those involved in team science projects.

To foster the necessary conditions for team science, we need:

- Objective measures of an individual's effective participation in team science that can be used as 'currency' and that can be usefully compared to single PI mode research. This will empower researchers to undertake research in the mode appropriate to the research, unburdened by career development concerns.
- Training and opportunities for ECRs to experience team science and better equip them for their careers.
- Improvements in the clarity of career paths and development opportunities for researchers from diverse backgrounds with specialist skills, who often play key roles in team science– for example, as skills specialists.
- Funding that encourages the best possible team science over sufficiently long periods of time, and provides career development opportunities and appropriate resources for project co-ordination (e.g. supporting project leaders and managers).

This will require:

- Recognition of and support for the varied roles necessary for effective and excellent team science.
- The development of evaluation practices that accurately capture key information about these roles, which will provide a 'currency' in evaluating the contributions of individuals involved.
- The collation and open dissemination of this information in a form that is simple, open, standardised, reliable and trustworthy.
- The development and implementation of contribution information systems for publications, grants and engagement activities.
- The development and implementation of contribution information systems for protocols, experimental material, software and large datasets.
- A culture change to use this information in a transparent and standardised manner to inform career-relevant decision-making, i.e. in recruitment, promotion and grant appraisal. This will require changes of policy and practice by employers and funders as to how individuals are appraised.
- The establishment of a 'single entry multiple use' system to digitally record researcher activities, roles and outputs. All information, such as that required by funders, employers and publishers, will be drawn from a digital portfolio owned and curated by the individual researcher. This will also improve attribution to funders and employers, and transform evaluation and monitoring activities.

Many elements of the system underlying our vision are already in place. In order to build on these and realise change we propose a broad timetable (Table 1) for implementing our recommendations. We plan to bring the various stakeholders together to assess the impact of this report in two years' time, and believe that the points highlighted below are achievable and measurable by 2018. The exact timing for the next UK Research Excellence Framework is not set but it is likely to take place in 2020 or 2021 and this seems an appropriate point at which to assess progress on recommendations that apply more to assessment mechanisms.

Finally, we recognise that a number of recommendations require significant change across multiple stakeholders and so we list those for 2022, allowing six years for them to be realised. We also recognise that, although the report has focused on the UK, team science projects often operate globally. To realise the aims we describe, the co-operation of international researchers, funders, employers and publishers will be required. We therefore propose involving the international scientific community in our two-year review.

Table 1: Proposed timeline for implementation of recommendations

Proposed timeline for implementation of recommendations

Year	Milestones	Anticipated outcomes
2018	**Two-year review of Team Science report**	• 80% of UK biomedical researchers have an ORCID • ORCIDs mandated by all major UK biomedical research funders • All major biomedical publishers enable inclusion of ORCID • Several publishers working with the research community to pilot contribution information framework for biomedical publications • Researchers routinely provide information to funders regarding roles on team science grants • Career development criteria and options for career paths are communicated clearly to researchers • Greater emphasis from employers and funders placed on leadership and more training for those leading team science projects
2020	**UK REF imminent**	• Grant reporting systems achieve interoperability with those of employers and employers' systems interoperate with others, such as ORCID • Funders have clear mechanisms in place to understand contributions to a grant and no longer require a single PI • Employers and funders use contribution portfolios in assessment processes • Ongoing active debate between publishers and researchers in how best to represent contribution information on publications • All employers offer training in team skills • Improved understanding of the role that skills specialists play in delivering team science
2022	**Post UK REF**	• Major funders have published reviews of their team funding approaches and consulted with researchers on meeting team science needs • Peer reviewers are being trained routinely in assessing team science applications and panels and grant managers are better equipped to support these applications • Funders foster greater responsibility among researchers regarding career development • Convergence of position between publishers and researchers in how best to represent contribution information on publications

3.2 Opportunities

New ideas and innovation often arise from research at the boundaries between disciplines. In addition, developing new ideas to tackle real-world challenges requires a wide range of skills and data that a single individual or team working in isolation may not have. Collaboration and team work is therefore essential.

The Nuffield Council on Bioethics surveyed 970 researchers for their 2014 report on the culture of scientific research in the UK. Many respondents stated that collaboration between scientists has the most impact on encouraging high-quality research, and drives the more positive aspects of research culture. The vast majority of the respondents were early career researchers in UK biomedical academia.[42]

Individual researchers benefit from participation in team science through:

- Widening their horizons and broadening their perspectives.
- Involvement in novel research projects.
- Producing more impactful research.
- Greater access to funding: some sources of funding are only available through a team science approach, such as the Human Frontier Science Program and most EU funding sources.[43]
- Acquiring new transferable skills applicable across sectors.
- Encountering improved networking opportunities for future career development.

However, team science is not the only approach that can yield high-value outputs– groups led by a single PI can be equally effective. Many written responses indicated that team science is not always the best approach for a given project: it should not be mandated by employers or funders, but facilitated and supported fully, where it is appropriate.

3.3 Challenges

Despite the opportunities outlined above, there are 'career development' challenges for individual researchers undertaking team science research, including:

- **The likely lack of recognition for individuals' contributions -** which is the overwhelmingly prominent concern for researchers.
- **The difficulty in finding funding that is sufficiently flexible and generous to facilitate excellent research involving adequate career development opportunities.** It is difficult to find sources of funding that are sufficient to fully support the needs of team science which include: contracts that are of sufficient length given the often longer timescales of team science projects; budgets that cover the services of support and administrative staff, regular meetings between collaborators and training for team members.
- **Inadequate team skills** and a lack of training in leadership and management, assertiveness, networking, managing bias,and resolving conflict.
- **Inadequate support from employers and funders for those staff critical to excellent team science, but who are not on a PI career track,** particularly 'skills specialists'.
- **Differences in the 'language' of communication between different silos such as the physical, biological, arts and humanities and social scientists.** We heard about a lack of senior peer recognition of individuals when they career-hop into other fields, especially in relation to career advancement within siloed professional bodies.

The opportunities and challenges for researchers participating in team science can vary depending on career stage. Having consulted researchers at all career stages, we realise that the fundamental concern about the lack of recognition of individuals' contributions to team science projects is the same, regardless of the stage they are at in their careers. However, ECRs are more vulnerable to the consequences of this lack.

3.4 Recognition

The main challenge for individual researchers participating in team science was overwhelmingly identified – by employers, funders, publishers and researchers themselves – as the likely relative lack of recognition for their contributions.

This is important: considerable effort is required to build and maintain a coherent and functional team – including identifying high-quality (expert, reliable and trustworthy) collaborators, and troubleshooting differences in opinion and priorities throughout. Despite this, for most participants, research assessment tends to undervalue the experience they gain from team science. Researchers at all stages reported that many of the roles and activities critical to team science are not recognised and evaluated in career development. This was echoed in a recent Nature article which argued that the team members, such as bioinformaticians, need to be better rewarded and recognised, stating that *'biological data will continue to pile up unless those who analyse it are recognised as creative collaborators in need of career paths'*.[44]

These concerns arise because career development currently relies on a research(er) assessment culture that is based upon two 'currencies' above all else: first and last author publications and 'lead PI' status on grants. A dismissive attitude toward 'middle authors' was reported in both biosciences and the humanities. Focus on these currencies disfavours those who have participated in team science because:

- They are more difficult to secure as group size increases.
- Information conveyed by author position and status on grants is a course-grained and inaccurate representation of contribution.
- Key roles in team science are rarely accurately described in the scholarly record, rendering the allocation of credit, and accountability, impossible. This is reflected in the attempts to expand the number of first and last authors in papers, where allowed, by journals. Moreover, some key roles and activities are not captured, such as project co-ordination, management, technical support and the development and maintenance of software and databases.
- This limited ability to define the contribution of individual team members erodes fairness and trust between team members, leading to conflict and hampering their ability to undertake excellent team science.

Thus, the attribution of multiple/various forms of credit for contributions will be essential if portfolio careers, crossing academic and industrial boundaries, are to be supported. The negative impact of current practice falls most heavily on ECRs.

This strong cultural bias continues to be driven by employers and funders emphasising the importance of individual researchers demonstrating 'leadership' and 'independence' (often defined in a way that makes these difficult to 'earn' via participation in team science). This was identified multiple times as a key factor in maintaining this culture, which limits opportunities for alternative and unconventional career paths.

It was reported that this culture is evident in the activities of employers, funders and honorific bodies, such as National Academies. It was further identified that the role of researchers as members of appointment and promotion panels, on funding panels and as peer reviewers means that this culture arises, at least in part, from within the research community itself.

Tackling these deeply embedded cultural values effectively will require action across all stakeholder groups.

The Nuffield Council on Bioethics report *The culture of scientific research in the UK* identified that the main driver of the more negative aspects of research culture – as reported by researchers –is research assessment (including national exercises like the REF, but also within the context of funding and employment), with its focus on first author or last author publications.[45] We heard that the perceived view in the sector is that various metrics, including both the REF and league tables, reward a single discipline mentality and therefore bias against team science. We are aware that attempts were made in REF2014 to address this issue by reducing the number of assessment panels compared with those for its predecessor, RAE2008. Many HEIs made joined-up submissions, for example, nursing with professions allied to medicine. Another issue raised was the potentially inadequate recognition of one's contributions to team science by peers within one's own discipline, in part because of the difficulties of assessing the work relative to work within the discipline.

3.4.1 Contemporary research appraisal – what is and isn't recognised?

Contemporary evaluation does indeed focus on first and last author publications, and principal PI status on grants. An important reason for this focus is the desire to use a simple metric from trusted sources: peer review and editorial/grant panels help ensure that these pieces of information are trustworthy – although they do not guarantee that this is so.

Grant income, rather than grant output, is measured since few funders make end-of-grant reports public. As a result of these practices there is an information deficit. Publications and grant income are often the only data that the research community is asked to provide, and therefore the only information available for evaluation. This information deficit was raised as a concern by most, throughout our engagement: the lack of better, more comprehensive information may drive the current evaluation culture. Additional relevant information is already collected within the research system (e.g. activities reported through Researchfish such as collaborations, public engagement, and financial impacts). However, the lack of interoperability between various research information systems is a barrier to the aggregation and use of this information, and results in unnecessary duplication of effort for researchers in providing it.

3.4.2 Has another field already solved this issue?

During our engagement and evidence gathering, some individuals in the biomedical research community suggested that particle physics, with experience of huge projects, such as those undertaken at CERN, has already solved the problem of ensuring fair recognition for those involved.

However, upon further investigation, the situation is less clear. Comments we received from a small sample of UK particle physicists working at CERN echoed the findings of a 2008 study titled *When authorship isn't enough: lessons from CERN on the implications of formal and informal credit attribution mechanisms in collaborative research*, which found that the *'community has largely turned away from formal records of contribution and taken to using informal means of assessment and evaluation'*, that *'it is also quite easy to get lost or even crushed in the crowd of a large…collaboration. Breakdowns in informal systems of recognition, of course, are not a novel result on their own. What distinguishes the present discussion is the almost complete absence of a formal record to fall back on'* and that *'physicists interviewed in the present study, particularly those at early stages in their careers, were significantly concerned about how to get adequate credit for their efforts and establish their reputations'.*[46]

3.4.3 Recognition on outputs

Here, we focus on two issues:

- How to improve recognition via generating and aggregating contribution information, focusing particularly on publications and grants as the most pressing first steps, whilst recognising that other types of contributions need to be described and evaluated.
- How to drive the use of that information in career-relevant decision-making by employers and funders.

3.4.4 Publications

The first step to ensuring that there is appropriate recognition of the contribution of authors on publications is to decide what constitutes authorship. Many journals have developed their own bespoke guidelines relating to the requirements for authorship. Currently, different fields have different traditions relating both to the definition of and requirements for authorship and the 'meaning' of individuals' positions in author lists (Box 3).

In biomedical sciences, the convention is that the first and last authors have made the largest contributions, while those in the middle, particularly when the number of authors is higher, are less able to claim credit. This arrangement is rooted in an era of smaller group research, wherein contributions and credit were clearer. Interpreting intellectual contribution from short lists is simpler, and can be reasonably reflective of individuals' contributions. The rise of team science has broken the 'first and last' system: it is no longer fit for purpose. Efforts to list several first and last/corresponding authors do not solve the issue for the 'middle' authors and do not resolve all disputes (who is first 'first' and last 'last'?).
Thus, they reflect, rather than solve, a growing problem. The linear authorship list does not take into account contribution timescales in team science: researchers may join and leave the project, with postdocs often finishing the work of their predecessor, presenting a challenge for recognition and attribution of credit through the current system. A survey of promotion and tenure committee chairpeople from

academic biomedical research in North America demonstrated how the current paradigm of author position is poor at communicating individuals' contributions for the purposes of career-relevant decision-making.[47]

Box 3. Authorship rules – practice from different fields

There is no universal definition of authorship.[48] The International Committee of Medical Journal Editors (ICMJE) has developed authorship rules that have been adopted by many biomedical journals.[49] Many journals have also developed their own guidelines.[50] According to a study presented at the annual meeting of the American Sociological Association, one-third of papers in the biological, physical or social sciences had at least one author whose contribution did not meet some definitions for co-authorship.[51] The changing nature of research evaluation, and incentives to increase the author list, have added to the lack of consensus on what constitutes authorship.[52]

The sequence of authorship in a publication can be a contentious issue. Authorship positions can have different connotations in different research disciplines. The perceived contribution of authors can vary based on byline position and number of authors.[53]

- **Authorship in the life sciences:** Conventionally, in the life sciences, the most significant contributor (usually a post-grad or postdoc) is the first author whilst the individual who designs and oversees the study (usually the PI) is the last author. Other researchers take up the middle of the author list.

- **Authorship in economics:** The author list is in alphabetical order, so no precedence can be interpreted.[54]

- **Authorship in engineering:** The protocol for authorship positions in engineering (specifically aerodynamics and computational fluid dynamics) is that authors are listed in the order of descending percentage contribution. The first author is always the primary contributor (usually a post-grad or postdoc), and while the PI may be in the last author position, this is generally if they are the most minor contributor.

- **Authorship in high energy physics (HEP):** In HEP, all members of a collaboration are traditionally listed alphabetically as authors on any paper published by any member of that collaboration. Names may include engineers as well as researchers. Other researchers take up the middle of the author list.[55]

There are some scenarios in which the lack of recognition via publication can be partly offset by ensuring that each participant obtains their own first/last author publication, as well as the team science publications. For example, in large genetic analysis projects, smaller 'offshoot' projects can be undertaken using the dataset produced by the larger collaboration but this solution is unlikely to be widely applicable. Alternatively, we heard that individuals can 'take turns' being first author – however, if the contributions to each paper are equivalent, but the papers are differentially cited, this can result in an imbalance in the career development 'currency'. Not all contributions to team science can be captured adequately by inclusion in publications or grants – for example, sharing of datasets or software, securing patents, or team and project management. These contributions – although essential to success – are often not described and are insufficiently valued, and therefore disincentivised. In addition, publication strategies are often driven by career consideration rather than effective communication of the science. We heard that ECRs involved in team science can be more vulnerable to this issue, and they may hold off publishing research in the hope of pursuing publication opportunities in journals with higher impact factors.

The focus on publications also compounds known problems with publication bias: replication studies and negative results are often difficult to publish, although they may be critical for large team projects. There is some evidence to suggest that publication bias is a result of the failure of researchers to submit negative results for publication, rather than an inherent bias by journals against such studies.[56]

The discipline-specific nature of many journals was felt to create a barrier to publishing interdisciplinary team science manuscripts. This can lead to a requirement for individual teams to 'tease out' papers that can be published in their own single discipline journals. We also heard concerns about ensuring adequate peer review for interdisciplinary team science papers.

The inaccurate allocation of credit through the current, non-transparent system is further compounded by: senior figures who 'automatically' receive 'last authorship' due to hierarchy; gift authorship, whereby individuals who were not involved in the project are listed as authors, perhaps for political reasons; strategic ordering, wherein individuals are positioned as first author simply because they are approaching a career transition; and ghost authorship, where certain critical roles are seen as 'service provision' and are left out completely from first (or any) authorship. Regarding the latter, we heard that these individuals, for example, imagers, statisticians and pathologists, sometimes have to be forceful to ensure they are even acknowledged in publications.

Through our engagement, we found that ECRs tend to be particularly concerned about authorship, especially where they feel they have little power/say in the project, whereas more senior researchers can sometimes be less concerned, and even dismissive of the ECRs' concerns. These points are reflected in a 2012 article titled *It is time for full disclosure of author contributions*, which stated that *'Sophisticated readers know that decoding an author list in terms of actual contribution to the scientific paper is close to impossible, unless you are involved yourself. Students find that they have to contribute much more to be listed as an author than more senior researchers do. Initially, students can feel exploited, but they may get used to the system. Eventually, if they choose an academic career, they may (more or less willingly) adopt the behaviour themselves. Political and personal relations also determine whether a contributor appears in the list of authors or under Acknowledgements'.*[57]

We heard of concern about the lack of contribution information available for those appraising researchers' track records. For example, the REF2014 Main Panel A Overview report contained the following comments from the International Members: *'In practice, there were additional efforts required to ensure proper author contribution to multi-authored outputs; and for the next REF these issues will need to be examined carefully and modified to promote large-scale collaborative research (which is likely to increase)'.*[58]
We heard that this information deficit was a topic of considerable debate in the biomedically-related REF panels – it was easier to judge outputs (publications) fairly when contribution information was provided.[59]

We found that the responsibility requirement of authorship (Box 3) is unrealistic and impractical for diverse team science projects. Researchers reported that being held responsible for the work of collaborators in other disciplines acts as a disincentive to participation in team science. It was noted that improved allocation of credit would result in improved allocation of responsibility, and could allow such requirements to be relaxed, helping to remove a barrier to team science participation.

Some elements of the current system may be unavoidable. There will always be a need for verbal shorthand when referring to a publication. However will it always be necessary to have a 'referred-to' author, who will end up accumulating disproportionate credit through association? This current situation drives concerns about who will be the first 'first' author where there is the capacity to list multiple first authors.

> "Academic recognition must embrace a fundamental change: it must provide improved information about the contributions of individual team members and use and value it in assessment.

3.4.5 Improving contribution information on publications

As argued above, the current system means that the actual role of each participant cannot be readily determined on multi-author papers, despite a range of 'unspoken' conventions, such as position in the list. However, it should be possible to provide an additional layer of information outlining the role of each author. We are aware that efforts at enabling so-called 'contribution information' have been ongoing for the past two decades.[60] These have had varying degrees of traction to date but, with the development of the necessary taxonomy and new technical platforms that allow for peer-approved statements of contribution and a greater willingness from publishers to embrace and implement such systems, we are assured that a more joined-up approach is possible.[61]

Bibliographic conventions for representation of authorship lag behind the semantic capabilities of the web and tend to obfuscate the contributions of those involved in collaborative research and writing endeavours. There is growing interest among researchers, funding agencies, academic institutions, editors, and publishers in increasing both the transparency and accessibility of research contributions. Many publishers now require contribution disclosures upon article submission – some in structured form, some in free-text form and concurrently, funders are developing more scientifically rigorous ways to track the outputs and impact of their research investments.

Describing the role and contributions of individual authors is not necessarily for publishers to solve, and requires broader participation from the research community to agree how best to describe author contributions (Box 4). The publishers we engaged with indicated that it is technically feasible to deliver a standardised mechanism for transparent allocation of contributions. It would take co-ordinated work to deliver this technical implementation, but the end result would minimise the researcher reporting burden, and ensure a more comprehensive implementation, since publishers work autonomously for the most part.

We conclude that a standard system for describing individual author contributions to publications is essential, and should incorporate the following features:

- Standardised categories of contribution, so that individuals encounter the same system in all work, whether as a researcher or an appraiser.
- Guidelines on how to allocate contributions in a transparent and consensually agreed manner.
- The allocation of contributions needs to be agreed by all listed on the publication upon submission to ensure accuracy and fairness, and to disincentivise the appearance of guest or honorary authors. Any changes will also need to be agreed by all those listed. Alongside the information being 'authorised' by the publisher, this will be necessary to provide appraisers with confidence of the information's accuracy.
- The system must link to other research information systems by capturing individual digital identifiers for everyone listed on the publication.
- The system must be as simple as possible, whilst remaining fit for the purposes of researchers, employers and funders. This was particularly important for funders and employers.
- The contribution information must be prominent and easily electronically accessible.
- Our researchers' workshop suggested a change from the current format, such as a grid or heatmap layout as a way of visually summarising an individual's contributions.

There was considerable discussion about how to communicate the magnitude of each individual's contribution, which is currently inferred from author position in the biomedical sciences.[62] This could take the form of a quantitative description, such as percentages, or a qualitative description, such as identifying 'principal' or 'major' contributors in each category. Many researchers felt that qualitative descriptions were necessary for the purposes of fairness, to differentiate those who did the 'heavy lifting'. Another suggestion was to ask applicants to include a clear 'organisation chart' in applications for funding displaying the structure of the team, the relationships and relative ranks of each participant, the responsibilities of each participant and the process by which decisions are made. Although one might expect that appraisers would support this, for the purposes of understanding individuals' unique contributions, funders and employers were not clear how they would use such information.

It was recognised that it may be difficult for a single taxonomy to accommodate all disciplines and scales of research collaboration. However, it was felt that the opportunity for such universality should be explored fully. Funders have their own interest in introducing comprehensive recognition systems: ensuring appropriate credit for a researcher will help to ensure appropriate credit for their funder.

Box 4. Current efforts to disentangle author information

Publishers currently vary greatly in asking for contribution statements. This was covered in a recent article which reports that: *'Some publishers, such as the American Association for Cancer Research (AACR) and the Public Library of Science (PLOS), ask authors to select roles from a predefined list. Others, such as Nature, invite or require free-text contribution statements, yet many publishers who collect role information from authors do not even publish it.'* [63]

Project CRedIT (contributor roles taxonomy): Project CRediT was initiated following a joint meeting co-hosted by the Wellcome Trust and Harvard University in 2011 to discuss how to move beyond a paradigm of 'authors' on scholarly published work, to be able to better represent, identify and understand who did what in contributing to scholarly work. Working initially with members of the ICMJE, the Evaluation Team at the Wellcome Trust and Harvard University worked to develop a taxonomy of roles that would be simple to use but could represent the range of contributions to scientific published outputs, initially focusing on biomedicine. In addition to providing more transparency about the contributions to scholarly outputs and allowing researchers to be identifiable and gain credit for their contributions, greater granularity around research contributions is likely to bring about a range of other benefits including supporting peer review identification and potential collaborators and helping to reduce the volume of author disputes currently managed by journals.

A 'contribution type 'taxonomy' was developed with input from across the scientific community and is now openly available, and being used in practice. The CRediT Taxonomy (and standards and guidelines for using it) is now being hosted by CASRAI (Consortia Advancing Standards in Research Administration Information) which aims to improve the flow of information within and between research stakeholders.[64] CASRAI is currently supporting the Project CRediT chairs to encourage and review implementations of the taxonomy and increase uptake by publishers, researchers, funding agencies, and academic administration workflows.[65]

There have been several live implementations of the contributor roles taxonomy to date, including by Mozilla Open Science, who have implemented the taxonomy using their 'open badges' approach, which has now started to be used by some journals and is linked directly to ORCID.[66] Cell Press have been offering the taxonomy as a format for submission of author contributions across their journals since July 2015; other journals look set to follow, introducing a structured list for 'author' contributions into their manuscript submission systems in early 2016. Aries Systems, a publishing manuscript submission system used by many journal publishers, is also introducing the taxonomy (in a structured list format) into its next system release for journals to optionally adopt.

FORCE11: FORCE11 is a community of scholars, librarians, archivists, publishers and research funders that aims to bring about a change in modern scholarly communications through the effective use of information technology. The FORCE11 Attribution Working Group was formed out of the FORCE2015 Contribution and attribution in the context of the scholar workshop. As described on their website, the Group was formed to:

- Collate and review existing efforts on scholarly contribution taxonomies.
- Determine if a consensus implementation, which would meet the requirements for all projects and would include the capability to be extensible from a core taxonomy is possible.
- Attempt to develop and pilot test the consensus implementation.[67]

It was noted that as long as an 'author list' is presented on publications, it will be difficult to drive usage of the detailed contribution information in appraisal of those involved in team science projects – appraisers will probably fall back to tradition and 'read into' author positions. While we acknowledge that ongoing discussion and debate about the risks and benefits of a new system will be required, we would expect a period of transition during which contribution information platforms are tested and begin to replace position-based author lists.

Wherever names of individuals are presented without their associated contribution information, the following approaches could be explored, to reinforce to the reader that author contributions can only be discovered from the detailed information available, not the author order:

- Randomising the author order for each publication.
- Using consortia names, instead of individuals e.g. 1000 Genomes Project Consortium would overcome the problem of the first author association due to the nature of citations (name *et al*).[68]

A study in the economics field revealed that alphabetisation resulted in first authors appearing to have better career development, so we do not consider this an effective option.[69]

The concept of developing and using a standard system for structuring contribution information across all publishers was strongly supported by all groups that we engaged with – particularly ECRs. Employers and funders were supportive but stressed the need for the information to be relevant to them, and presentable in usable and simple forms, for example easily accessible on PubMed.

This type of system would make it possible to link the contribution information (potentially/ideally in the form of metadata tags) to the article's digital object identifier (DOI) and to individuals' digital identifiers (e.g. ORCIDs).

3.4.6 Grants

The current system

Usually on grant applications, a single researcher is listed as the PI, and in some cases with designated co-investigators. We heard that, similar to first or last authorship, PI status is taken as unambiguous evidence of leadership and credit, with less recognition for the co-investigators.

We heard that the hierarchy of designations (principal and then co-I) is useful to funders for the purposes of accountability – a single individual is then responsible for the project's leadership, proper conduct and financial management. Often a desire for accountability and simplicity results in a system with only a limited number of formal roles on the grant. Whilst responsibility for leadership and conduct can be shared out, UK funders were keen to have a single individual, at a single host institution, who could take responsibility for the financial management of the project. Funders cannot be employers, due to resourcing and legal issues, nor can they mediate disagreement between PIs about the distribution of funds. Other models that allow accountability do exist, such as large-scale European Union grants which are distributed from a central pot to multiple institutions, have distinct work packages, with identified leaders of each work package, and which enable more detailed contribution information for individuals on grants.

We also heard of the problem of key team members not meeting the eligibility requirements for grants, to the detriment of their future career prospects. Some funders stipulate that only permanent staff can be listed, thereby preventing postdocs on fixed-term contracts from being included. However, postdocs can be named co-investigators on UK Research Council grants. Also, caps on numbers of co-applicants/investigators can disadvantage those in larger teams, as all relevant individuals cannot be listed.

This situation presents a 'credit' problem analogous to that with publications: unless a range of roles are identified on the grant, and 'ordering'/hierarchy is removed from individuals' designations, the diverse contributions necessary for excellent team science are not being recognised.

Improving contribution information on grants

Grant administration and reporting should be developed to capture all of the roles performed by the project's key participants. Importantly, nomenclature that leads to inaccurate allocation of credit needs to be avoided. One option is to list all individuals as 'co-investigators'. Structures that specify 'work package leaders' could afford the opportunity to provide formal recognition of key, but often unrecognised, contributions. For example, one work package on all large grants could be 'project management'.

3.4.7 Recognition of other types of contributions

As mentioned previously, the Working Group decided to focus on publications and grants as the most pressing first steps, but recognised that other types of contributions, such as data sets and software need to be described and evaluated. In the future, action should also be taken to capture the other types of activities and roles outlined in Box 5.

Box 5. Recognition for other types of outputs

There is growing awareness of a need to recognise research outputs other than publications, particularly given the increasing prevalence of digital outputs such as software and databases. To be of use to the research community, such outputs need to be widely accessible; requirements by funders to make publications open access, and datasets freely available, support this aim. However, existing models of appraisal for employment and funding generally require researchers to maintain tight control of their data in order to demonstrate authorship and receive credit for their work.

New systems for recognising and crediting the variety of research outputs are needed to resolve this conundrum. There is widespread support for the development of such systems, as evidenced by the **San Francisco Declaration on Research Assessment (DORA)**, which stresses the limitations of journal-based metrics and champions the value of alternative research outputs; the **Expert Advisory Group on Data Access (EAGDA)**, which provides guidance on how access to research data should be regulated; **DataCite**, which provides citation for data, and the **Research Data Alliance**, which convenes working groups to design new mechanisms of sharing data. Although much work remains to be done, new models and systems are already being developed. Several examples are described below.

- *Software:* Software is often stored in, and accessed through, repositories such as **GitHub, CRAN, PyP**I and **Boost** or on discussion forums for various coding programmes (for example, http://uk.mathworks.com/matlabcentral/). Products stored in these repositories can be copyrighted but are usually made freely available for general use.

- *Databases:* There are many discipline-specific databases. Examples include the **Gene Expression Omnibus (GEO)** for functional genomic data; the **Protein Data Bank** for protein structures; **PANGAEA** for earth systems research, and the **UK Data Archive** for the social sciences and humanities. The **Data Citation Index** goes a step further: it aims to provide a central access point for databases across the disciplines, to put research in the context of related work and to track attribution for digital data.

- *Alternative models of attribution*: In a recent article in the Journal of Open Research Software, Daniel Katz proposes 'transitive credit' as a new approach to attribution of digital products.[70] In this system, a percentage credit is assigned to each contributor to a research output (such as an article, a piece of software or a dataset). This percentage is then carried through to subsequent uses of the product. All aspects of a digital product – its creation, maintenance and use – are cited under this scheme. In addition, initiatives such as **ORCID, Researchfish, AltMetric** and **Spliddit** aim to improve recognition of researchers' work by tracking and recording a wide range of research outputs and assigning fair credit to contributors.

As we move forward, opportunities will be developed to capture all of the roles and activities that constitute researcher 'citizenship', such as peer reviewing, grant writing, mentoring, teaching,and public engagement. Thought will be needed as to how types and magnitudes of contributions could be captured, how researchers' approval of contribution information would be obtained and how the information could be 'authorised' and accepted with confidence.

3.4.8 Creating portable digital contribution portfolios

ORCID is now the clear frontrunner in the individual digital identifier space (Box 6). It is being mandated by funders and journals and adopted by a large consortium of HEIs in the UK.[71] With the ability to link researchers' outputs with their individual identifier, it becomes possible to add contribution information. While making the information publicly accessible and open and using trusted sources does not eliminate the possibility of fraud, it makes it less likely.

However, individuals need to control their online 'profile' – i.e. deciding which outputs they 'claim' and making sure it is up-to-date. Ultimately this will become a single-entry multiple-use central dataset. University research information systems and funder evaluation systems, such as Researchfish, could use the identifier to aggregate a contribution portfolio for an individual, which could be used to inform career-relevant decision-making. Contribution portfolios aggregated via ORCID could also be represented in multiple ways for multiple purposes, to inform review panels or to help individuals planning their own personal development, using something like the 'heatmap', mentioned earlier.

Digital portable contribution portfolios would create benefits beyond individual career development. They would allow credit to be more easily defined for funders and employers. They would also revolutionise monitoring and evaluation, as more 'fine-grained' data on individual careers would all be collected and made available through the central dataset. This system should be used for all new outputs and activities. Once such a system is in place, consideration could be given to incorporating legacy information (e.g. previous papers and grants).

3.4.9 Changing decision-making by employers and funders

Presenting better information is only one side of the equation. Changing how information is used and valued in career-relevant decision-making is the other. Decision-making must still focus on excellence, requiring intellectual contributions and leadership to be captured, as well as team citizenship and the 'doing of the work'. Funders and employers must use information about varied contributions in their decision-making. They must develop transparent evaluation criteria and communicate them clearly to researchers. When doing so, funders and employers should bear in mind some points that we heard: the danger that an individual may be perceived as doing 'less' when participating in team science compared to leading a single-PI project, although the work could be objectively more sizable and impactful; and ensuring interview stages in decision-making processes allow researchers to describe better the experience and expertise they have gained via team science.

Many of the individuals making career-relevant decisions regarding others have a range of competing demands upon their time – and while some argue that the use of metrics and simple rules of thumb, such as author order, save time compared to evaluating more complex/detailed information, most people would value additional information in order to make an informed decision. We recommend that contribution information should be presented in a simple and intelligible manner.

Box 6. Building an interoperable system of information on outputs and contributions

ORCID

ORCID (Open Researcher and Contributor ID) is an open, non-profit, community-driven effort to create and maintain a registry of unique researcher identifiers and a transparent method of linking research activities and outputs to these identifiers. As described on its website, ORCID provides two core functions: (1) a registry to obtain a unique identifier and manage a record of activities, and (2) application programming interfaces (APIs) that support system-to-system communication and authentication.[72]

Jisc (formerly the Joint Information Systems Committee, the UK research ICT body) and the Association of Research Managers and Administrators (ARMA) are planning to orchestrate ORCID 'consortium' membership for all of the UK, removing the need for each institution to register separately.[73] Thirteen UK higher education institutions are already ORCID members, and interest in consortium membership is building.

An independent review of RCUK open access recommended in late 2014 that RCUK adopt ORCID across all of its processes.[74] There have been similar recommendations/efforts in Australia (March 2015) and the US (2014).[75] The *Metric Tide* report calls for ORCIDs to be made mandatory for all researchers in the next REF.[76] The Wellcome Trust has mandated ORCID as part of its grant application process.[77] The NIHR has recently made ORCID mandatory for all new NIHR personal award applications.[78] The MRC are working on ORCID integration with their grant systems.

Figure 3 shows how automatic updates of records can be achieved using interoperable identifiers (i.e. the ability to exchange information in both human and machine readable formats).[79]

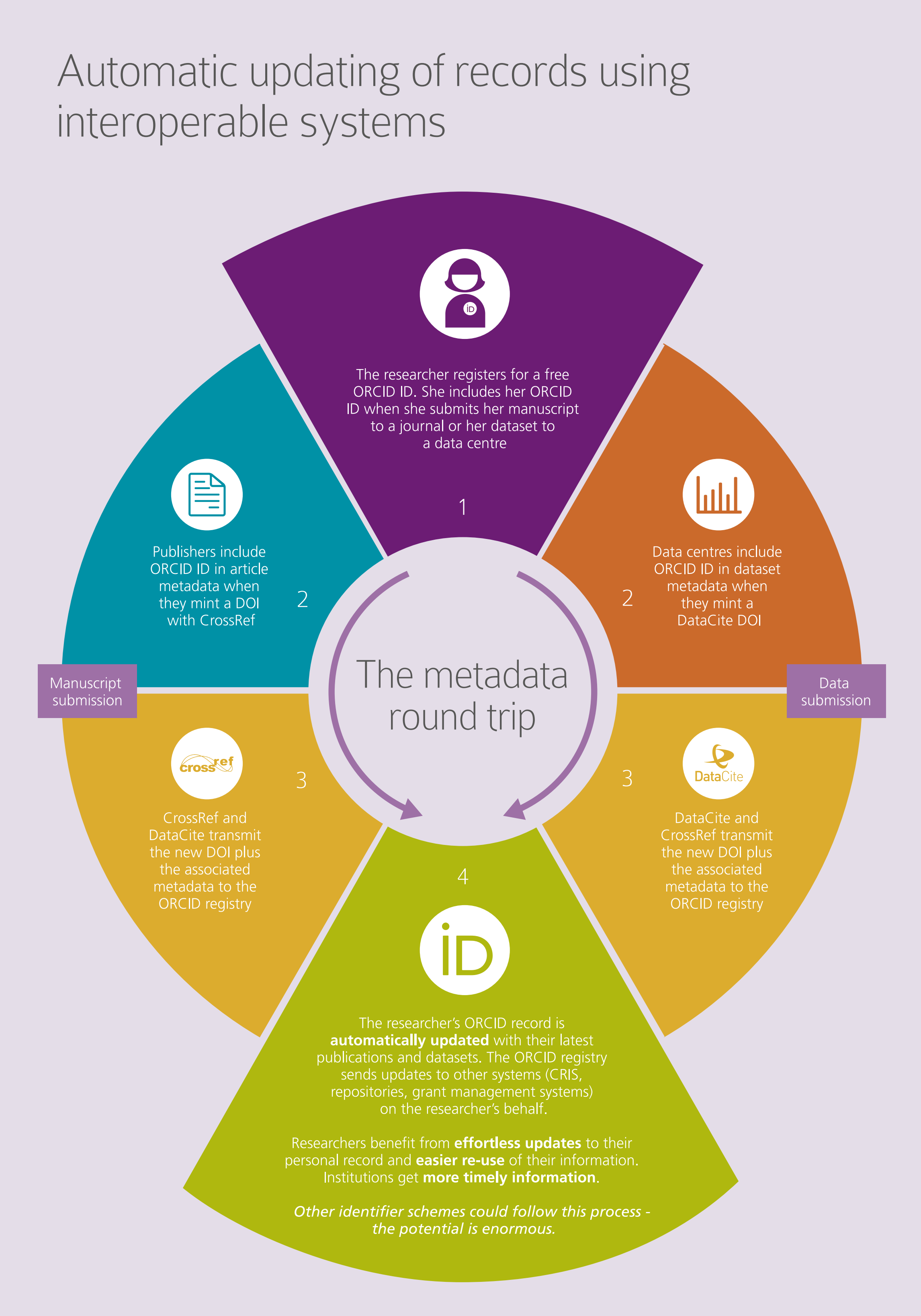
Funder information

Funders have an ongoing interest in the outcome of their funded projects, so they have begun to design processes to systematically collect output information. **Researchfish** is an online service which operates for UK funders, institutes and researchers to standardise and collect research outcomes.[80] It is currently used by over 100 funders and research institutes. All seven UK Research Councils now use Researchfish and require their funded researchers to submit Researchfish returns in 2015/16. Information returned to the Research Councils through Researchfish is made available through the **Gateway to Research**.[81] RCUK is actively working with Researchfish Ltd to implement better interoperability with the research information systems used by research organisations. Some funders have developed their own bespoke systems, such as the Wellcome Trust e-Val, the Trust's online portal for grantholders to report on their funded work.[82]

University information systems

There are a range of university databases or information systems such as CRIS (current research information system) and PURE (**pu**blication and **re**search) designed to help with the information management of research activity conducted at an institution.
There is already work underway to achieve interoperability of Researchfish and university information systems such as PURE. We have heard that there will ultimately be interoperability of university systems, Researchfish and ORCID.

Figure 3: How automatic updates of records can be achieved using interoperable identifiers



DOI: digital object identifier

Employer specific points
As well as rewarding those who obtain research grants, universities should ensure that individuals who contribute to publications and other outputs, or who catalyse impact, are similarly credited. While end-of-grant information provides important baseline data, the lag time until all outputs emerge varies depending upon the research area and the nature of the project, and may be particularly lengthy for long-term team science projects. Funders and employers should therefore be prepared to track outputs over time using services such as Researchfish in the UK.

Employers should request and use information from an individual's contribution portfolio. They must also define what value they associate with team science contributions and update their promotion criteria accordingly, clearly communicating these developments to employees. In doing so, it is important that performance reviews reflect the responsibilities of the individual concerned. For a senior PI it should go beyond their ability to obtain grants to a consideration of how they have managed their resources and staff, e.g. if they have supervised PhD students and postdocs, understanding their career progression would be useful.

Funder specific points
Similar to employers, funders must request and use contribution portfolios, and develop and publicise clear frameworks for how they are used in decision-making. Funders must induct and train panel members and peer reviewers, as appropriate, in how to value contribution information to team science projects. Funders must also ensure that panels have an atmosphere of challenging 'old school' first/last author mentality.

Recommendation 1

All research outputs and grants should include open, transparent, standardised and structured contribution information.

- *Publishers* should work with relevant initiatives, such as Project CRediT, and the research community to develop, pilot and evolve a standardised contribution information framework for publications.
- To ensure that the information captured is fit for their respective purposes, *employers*, *funders* and *researchers* need to engage with publishers in developing the framework.
- For team science grants, *funders* should phase out any requirement for a 'lead' or 'principal' investigator, and list all applicants as 'co-applicants'. *Funders* need to develop and publish clear criteria for co-applicant status. In addition, we recognise that *funders* may require one co-applicant to be identified as the 'administrative lead'.
- *Researchers* should be required to provide a statement describing the contribution of each co-applicant to the grant.

Recommendation 2

The most effective way of providing contribution information will be an open and transparent research information infrastructure which links all research inputs and outputs to individual contributors.

- *Researchers* should obtain an ORCID ID and link it to all their research activities.
- *Publishers* should ensure that publications include ORCID IDs for any associated inputs and outputs.
- As publishers do for publications, *data and software repositories* should also link to ORCID.
- Likewise, *funders* should develop and use publicly-accessible grant information databases, wherein each record is linked to ORCID.

Recommendation 3

Information infrastructure must minimise researchers' overall administrative burden and information systems should be interoperable.

- *Funders* should ensure that their application and grant reporting systems are interoperable with those of *employers.*
- *Employers* must ensure that their institutional research information systems are interoperable with publicly available databases, such as ORCID.

Recommendation 4

The use of 'key' positions on publications and grants as the primary indicator of research performance, leadership and independence in team science projects should be replaced by transparent, fair processes.

- *Employers* should use individuals' contribution portfolios when appraising them for recruitment and promotion.
- *Funders* should use individuals' contribution portfolios when appraising them as part of a funding application.
- Both *funders* and *employers* should update their criteria for career development at all stages. This information should be available publicly and communicated clearly to all researchers.
- With the phasing in of contribution information on publications, *researchers* and *publishers* should engage in active debate about phasing out author listing traditions for team science projects.

3.5 Funding

3.5.1 Configuration of funding opportunities: balance, flexibility, length and magnitude
The question of striking the right balance between team science and single PI funding within their own portfolio was raised by funders themselves – and the need to support both sufficiently came up throughout the project.

Due to the co-ordination required, team science is usually more complex to organise than single PI research. The most prominent concern voiced by researchers and employers was the need to ensure that team science funding is more flexible, and of the right length and magnitude to allow effective research and career development, thus incentivising participation. In particular:

- The duration of the grant should be sufficient to allow for the time it takes to build and continually co-ordinate a team.
- Resource is needed for the organisational/'indirect' components of the project, such as holding meetings to build trust, and employing project managers. It was often mentioned that structuring grants into work packages helps improve the recognition of project managers' critical contributions.
- Consideration should be made for the possibility that team science networks can be broken up by requirements or expectations, whether real or perceived, that researchers, especially ECRs, must move institution or country to obtain further funding.

It was also suggested that portable Fellowships should be embedded into team science grant applications. Researchers feel that such Fellowships are a valuable mechanism for individual researchers to flexibly participate in team science.

Funders should investigate whether their funding models support or discourage team science approaches (See Annex III). We are aware that the Global Research Council has already *'selected interdisciplinarity as one of its two annual themes for an in-depth report, debate and statement between now and mid-2016'*.[83]

There are a number of existing funding opportunities aimed at supporting team science; see Box 7 for examples.

Box 7. Examples of current team science funding

UK:

- **NIHR Translational Research Partnerships (TRPs)** *'bring together the UK's leading academic and clinical centres for experimental medicine and translational research into a ready-formed partnership of universities and NHS hospitals'.* Participating centres were selected on the basis of open competition. In addition, the UK Department of Health has provided £2.6 million to support the TRPs in developing collaborations with industry, led via the NIHR Office for Clinical Research Infrastructure.[84]
- The UK's seven research councils have agreed to work together to deliver multidisciplinary research in six priority areas to address the big research challenges, through a programme co-ordinated by **Research Councils UK.**[85]
- The **Wellcome Trust's Collaborative Awards** were launched in late 2014. They *'provide flexible support to excellent groups of independent researchers with outstanding track records. Proposals must address important scientific problems that can only be achieved through a collaborative team effort'.* Awards are expected to be up to £4 million.[86]
- A number of **charity-funded research centres** support team science. They often receive core funding in 5-year cycles.[87]

- **Cancer Research UK Multidisciplinary Project Awards** fund *'collaborations between cancer researchers and scientists from engineering/physical science disciplines'*. These awards are made to teams with a minimum of two PIs and cover up to £500,000 over four years.[88]

Europe:

- **Horizon 2020** is *'the financial instrument implementing the Innovation Union, a Europe 2020 flagship initiative aimed at securing Europe's global competitiveness'.* Projects in areas such as agriculture, biotechnology, environmental and climate science, and health can be funded through this initiative. The programme values team science approaches – many of the calls for proposals ask for a team of at least three collaborators.[89]
- The **Innovative Medicines Initiative (IMI)** represents *'Europe's largest public-private initiative aiming to speed up the development of better and safer medicines for patients'*. It has a €3.3 billion operating budget for a 10-year period, from 2014 to 2024. The Initiative seeks to foster collaboration among universities, the pharmaceutical industry and other businesses, patients, and medical regulators in order to achieve its aims.[90]

Global:

- **The Human Frontier Science Program (HFSP)** is *'an international program of research support, funding frontier research on the complex mechanisms of living organisms'.* A key element of HFSP's mission is *'the promotion of international collaboration in the spirit of science without borders'*.[91]
- Funding agencies in Canada have been emphasising strategic calls for proposals that are for teams and partnerships e.g. the **Canadian Institutes of Health Research (CIHR)** New Emerging Teams Competitions; **Natural Sciences and Engineering Research Council of Canada (NSERC)** Strategic Grants and Collaborative Research & Development Grants; **Social Sciences and Humanities Research Council (SSHRC)** Partnership Grants.[92]
- **CIHR's Industry-Partnered Collaborative Research Operating Grant Program** provides funding for collaborative research projects involving the academic community and Canadian industry partners sharing an interest in health R&D. The maximum amount per grant is $250,000 per year for up to five years.[93]

3.5.2 Oversight of projects

We heard that without clear aims and goals, team science projects can become ineffective and impact negatively on the career development of those involved. Although this is a responsibility of the researchers, it was suggested that funders build in and review opportunities to 'check-in' on team science projects to ensure that career development is being facilitated, and use mechanisms, such as milestone meetings and annual reports, for ensuring this.

3.5.3 Appraising team science grant proposals

Funders and others raised the difficulty in securing appropriate peer review for team science grant proposals as a prominent issue.

Experience and expertise of panel members and peer reviewers

Disciplinary breadth and experience of team science can be difficult to secure in panel members and peer reviewers. We heard that the single-discipline background of many reviewers and panel members means that a 'holistic' view of a team science application is often difficult to achieve. There was concern that risk-averse behaviour in making funding decisions disfavours team science. A number of comments suggested that panel members and peer reviewers may be the source of this behaviour.

It was suggested that skill sets of panel members and peer reviewers be evaluated – there were many calls to include individuals with strong team science track records on panels, and as peer reviewers. There was also discussion on whether funding panels should include more ECRs, as they may give a useful perspective and may also learn more at earlier career stages about grantsmanship. However, there was concern that ECRs may not have sufficient experience for the role, and it may detract from the time they need to establish their research profile.

Frameworks for evaluating interdisciplinary proposals
Evaluating interdisciplinary proposals is difficult, given that most evaluation criteria and processes are rooted in single discipline norms.

There were calls for improved mechanisms and support for panel members and peer reviewers in order to improve the appraisal of team science grant proposals. Suggestions included introducing/changing inductions, guidance and processes. There is already some progress in this direction: a draft framework for evaluating such proposals was published in 2015 following the *Evaluating disciplinary research* workshop at Durham University.[94]

3.5.4 Evaluating leadership

Excellent team science relies on excellent project leadership. There were consistent calls for funders to evaluate the 'team leadership' track records of those listed in key roles on team science grant proposals.

We considered whether consistently collecting 'leadership' feedback on project participants should be mandated as good practice for receiving funding – in the same way that, since 2011, good gender equality practice needs to be demonstrated (via achievement of Athena SWAN silver award status) for UK medical schools wishing to apply for NIHR biomedical research centre and unit (BRC/BRU) funding.[95] It was suggested that this could be achieved through '360 degree feedback' processes. However, although 360 degree review is used often in clinical researchers' clinical (rather than research) career development, care needs to be taken to appreciate the differences between, and keep separate, 'formative' feedback mechanisms (used to help an individual develop and become better at their job) and 'summative' feedback mechanisms (used to judge an individual in career-relevant decision-making).[96] We note that there are other complementary methods of assessment such as Wave profiling.[97]

We heard from some industrial researchers that it can be helpful to separate appraisal of technical and team skills. In fact, sometimes the appraisal of an individual's team skills is performed by someone outside of their team/reporting line.

Recommendation 5

Team science funding should provide the length, breadth and magnitude of support required by recognising the longer timescales often needed to achieve outputs and additional costs associated with effective team working.

- *Funders* should regularly review the balance, flexibility, length and magnitude of their funding for team science projects, and publish the outcomes.
- *Funders* should use the published outcomes as the basis for consultation with the research community on ways to improve team science funding.

Recommendation 6

Team science grant proposals need to be appraised holistically, as well as from the perspective of the relevant disciplines.

- *Funders* should review policies and processes for obtaining appropriate peer review and appraisal of team science grant applications, and make changes where necessary.
- *Funders* should induct and train peer and panel reviewers, as well as grant managers, to meet this challenge.

Recommendation 7

The value of project leadership should be evaluated when appraising team science grant proposals.

- *Funders* should evaluate the leadership track record of designated leaders on team science grant proposals.
- *Funders* should work with *employers* and appropriate expert bodies to develop clear, publicly-available guidance on relevant forms of evidence that could be used for this purpose.

3.6 Researcher practice

3.6.1 The responsibility of the individual

Within this report we have focused on the influence and responsibilities of stakeholders, such as funders, publishers and employers, in shaping national and institutional policies and practices to foster team science. It is equally critical for individual researchers at all career stages to demonstrate behaviours that contribute positively to the success of the team. Through our evidence gathering and engagement, a range of researcher behaviours and activities were identified that are crucial for undertaking successful team science that fairly allocates credit and supports the career development of individuals within the project. Such behaviours may seem to be common sense and intuitive but require a culture change that can be difficult to implement in practice. Our findings, described below, are echoed in a recent article:[98]

- The most important factor underlying successful team science is mutual trust between research partners, built on a foundation of openness and proactive communication. Researchers should strive to build trust at the outset and maintain it throughout the duration of a project. This is especially important in transdisciplinary teams where team members will not easily be able to validate each other's work.
- The most productive collaborations are built around the existence of shared objectives. In order to build cohesion and to protect the interests of all parties, collaborating partners must agree on milestones, credit and responsibilities as a team. These need to be flexible and reviewed throughout the project to reflect the evolution of the project and changes in the team. We heard that this practice occurs more frequently in collaborations with industry. We note that it is the team leader's job to ensure that discussions about milestones and credit occur, since junior researchers' power is limited in this area.
- Individual researchers working in teams need to be proactive in promoting and logging their contributions as the project progresses. This will ensure that credit is shared equitably. There may be value in developing universal guidelines on how best to do this, which researchers could follow. An example of good practice that was offered is of researchers at the Sanger Institute having initial meetings to decide on roles and using spreadsheets to log contributions.
- Encouraging a 'challenge' environment in the team, wherein all members feel comfortable suggesting and receiving constructive criticism from all other members across disciplinary, seniority and group boundaries, is fundamental to success in team science. Team leaders have a particular role in fostering a collegiate environment within their teams.
- Good quality networking opportunities are invaluable for researchers engaged in team science to help them identify potential collaborators and establish contacts with other academics. Researchers indicated that holding these informally, outside of working hours, can disadvantage those with caring responsibilities. For example, we heard of some concerns that as a group, women participate and lead less in team science. Employers have a responsibility to ensure that networking opportunities are organised within working hours, to minimise the bias against those with caring responsibilities. However, researchers must also be proactive in seeking out and taking advantage of such opportunities as much as possible.
- Researchers must provide mentoring and coaching to fellow team members, especially new or less experienced students or trainees, to foster a supportive environment for the conduct of team science. Mentoring allows more experienced team members to share their knowledge and skills on a range of scientific and career development issues. Multiple mentoring may be valuable, to expose team members to perspectives of various disciplines and specialities. Mentoring by individuals outside the team may be valuable as well, particularly for ECRs. For example, the Academy's one-to-one mentoring scheme provides postdoctoral biomedical researchers with career development support by pairing them with an Academy Fellow.[99]
- Fostering good academic 'citizenship' is another key component for successful team science. This entails partaking in 'invisible' duties and contributing to wider organisational processes such as mentoring and pastoral care; external examining; peer reviewing; organising conferences and seminars; sitting on editorial, promotion and funding panels; writing references; organising and developing teaching curricula; public engagement and outreach; serving national organisations; and sitting on committees.[100] Due to the difficulties of balancing research and teaching responsibilities, these duties are often perceived to be taking valuable time away from scientific endeavours. However, it was agreed by many of the stakeholders we consulted that academic citizenship should not fall off the agenda. Researchers must develop a sense of academic citizenship that brings wider benefits to the community and ensures that the overall load of service responsibilities is shared fairly.

Box 8. Examples of good researcher practice

Our call for evidence produced numerous examples of good practice, a selection of which are highlighted below:

- Pharmaceutical companies invest significant resources developing new medicines – a long and rigorous process, involving multiple teams with a wide variety of expertise. Companies plan for this carefully, using techniques such as gap analysis, to understand the skills required and to deploy those with the right expertise at the appropriate stages of drug development. Efficient onward development of any medicine requires that teams focus on their particular strengths but develop an understanding of the overall process, which requires strong co-ordination and collaboration at all levels.
  Large companies invest in training, development, support, and learning opportunities for their staff, as well as rewarding high performance and outstanding achievements with a range of financial and other benefits.
- Some laboratories (and collaborations) use points systems to distribute credit, and allocate authorship based on this.[101]
- Early career researchers who work in big teams could be supported by team leaders to write their own papers, in addition to working on papers which may have a large number of authors. These could be more discipline-specific. We heard that this approach is adopted by physicists working for CERN.
- As a group, the **MRC Unit for Lifelong Health and Ageing at UCL** has made a list of components for successful team science including: compatible agendas and common goals; agreement on and acknowledgement of value of each individual's contribution and role; mutual respect and trust; appreciation of other disciplines; high-quality joint scientific output that fairly recognises contributions.
- The **Institute of Cancer Research** runs various events to foster collaborations and team science across the organisation, including a 'collaboration speed dating' event for postdoctoral researchers to identify potential cross-discipline collaborations. They also have cross-disciplinary staff groups such as the Career Development Faculty, Postdoc Association and Scientific Officer Association.

We heard that while some ECRs welcome opportunities to explore new disciplines through team science initiatives, others view them as risky, possibly impacting negatively upon the chances of career advancement. Box 9 outlines some advice we received from researchers on how to thrive in team science.

Box 9. Advice from researchers on how to thrive in team science

In our call for evidence, we asked researchers the following question: 'Drawing on your own experience, what tips would you give a young researcher about how to thrive in team science?'

Below we outline a selection of the responses we received.

- Try to sit in on a project meeting that is not your own – to see how team science is done by others.
- Get a mentor who will support and advise you.
- Spend time seeking good 'team players' when you build your team – avoid 'bad' collaborators. Find out about the background of the group/person and make sure they are a good team player.
- Find your voice and do not be afraid to speak out. Be an active voice in meetings throughout, even if you hold a junior position, and be sure to argue your case when it comes to establishing author contributions.
- Have discussions early on to clarify goals and contributions.
- Communicate effectively. Be proactive about keeping in contact, and talk instead of email where possible – personal contact is key. Take the opportunity to network as much as possible.
- Try to foster reciprocity with your peers and others.
- Be open to different ways of thinking. Be enthusiastic about learning across disciplines. Get out of your comfort zone and get stuck in.
- Seek and undertake training in people skills, including leadership and project management.
- Establish a niche or skill that makes you important, perhaps even indispensable. Something where you are the lead and expert. Make sure you get recognition for this.
- Stay organised throughout.
- Document your contributions and build a portfolio that showcases them.
- Choose to work in an organisation that truly believes in the benefits of team science – fighting against the 'system' can be hard.
- Work on things you care about, so you can get pleasure from the work even if you get little recognition.

3.6.2 Role of team leaders

Team leaders have an important role in instilling the right atmosphere and behaviours into their teams. Indeed, they have a substantial role in influencing the collaborative process, and can lead by example. A successful leader of team science projects will need to set out clear expectations, ensure that all members are heard and acknowledged, connect disparate groups, mentor other team members, and possibly share leadership over the course of the project as the focus develops.[102] An additional important role of research supervisors is maintaining the contribution portfolio of their students and postdoctoral researchers and aligning it to any references they provide.

We heard that good team leaders are not necessarily those most often placed in that role, i.e. the most senior academic involved in the project. It was noted that in industry more junior scientists or those with less specialist scientific experience may be appointed to lead particular projects. Senior academics, as proposed in a recent Nature comment article, should be offered the opportunity to undertake training in effective leadership.[103] The authors themselves have delivered 'effective leadership' training for senior academics for many years, and reported that *'Professors tend to be sceptical about many things, and leadership is no exception. Over the years, we have heard many academic colleagues in engineering and science, especially senior ones, express opinions as to why soft skills are pseudoscience and should not be taken seriously'.*

Enabling good leadership may require the appointment of specialist project managers to ensure that the management aspects are attended to, so that the research leader can focus on strategic decision-making and guiding the team. An alternative approach, frequently adopted by industry, provides an employee with two managers – one technical or project-related, who may change when the project finishes and the other, a more traditional 'line manager' who provides a consistent overview of performance.

Recommendation 8

Researchers should drive change through their crucial roles as team members, peer reviewers and participants on recruitment, promotion and funding panels.

- **As team members, *researchers* should:**
  - Ensure that credit is allocated fairly and transparently.
  - Define clear areas of responsibility for all individuals involved at the outset in team science projects, and review these throughout.
  - Proactively seek feedback and gather evidence to demonstrate their leadership track record, based on funder guidance (Recommendation 7).
  - Obtain training in team skills (Recommendation 9).

"The most productive collaborations are built around the existence of shared objectives. In order to build cohesion and to protect the interests of all parties, collaborating partners must agree on milestones, credit and responsbilities as a team.

3.7 Training

3.7.1 The need for training

The need for training in team working and associated skills is becoming ever more important with the increase in team science. Despite this growth in team working, we heard that individuals (at all levels) often lack the skills required to contribute effectively to this way of working. Individuals and teams would benefit from training in assertiveness and group dynamics, communication skills, networking, how to form successful collaborations, project management, managing unconscious bias, resolving conflicts and the role of the team leader(s). Such training could have wider benefits through instilling the qualities required to become a better 'academic citizen' and in driving culture change to improve the recognition of team science contributions – for example, for peer reviewers or for members of funding/promotion/recruitment panels. It was suggested that, as a first step to address the issue, team skills should feature as a requirement in job descriptions. However, where these skills are lacking employers should be prepared to offer training for both new and existing staff.

3.7.2 Improving training

Through our engagement with researchers, we heard that although it is generally agreed that team skills are important, different institutions offer varying degrees of exposure to specific training opportunities. We also found that, whilst formal training is valuable if done well, the real training comes from direct experience of team science projects. Early exposure is key – as expressed to us by PhD students and ECRs. Therefore, employers should promote an ethos that encourages involvement in team science and spreads good practice, from undergraduate study onwards (Box 10). For ECRs, employers should provide focused and relevant introductory training in the areas outlined above: leadership, management, networking, conflict resolution and unconscious bias.

Team leadership training should be provided as a core part of career progression, particularly for PIs. It was noted that in industry, teams are often put together in an autocratic, top-down fashion and employees are expected to learn to work in this way, albeit with training and other incentives.

As a first step towards improving training, academic employers should identify best practice within and outside academia to inform their training programmes, and perhaps work to develop appropriate courses with a national training provider.[104] Recruitment and promotion review panels need to be trained to capture not just authorship contributions but also 'soft skills' which are critical for team science. We highlight here that employers need to ensure not to make such training feel 'remedial', particularly for more senior researchers. Our consultation also indicated that mentoring is particularly valuable, alongside training and exposure, to help researchers navigate team science and secure career development. It was suggested that personalised coaching is often effective as it is tailored to the strengths and weaknesses of individuals. Subject to evidence that they are effective, toolkits such as the one developed in the US in the field of oncology could be promoted in the UK.[105]

Box 10 outlines examples of training opportunities and exposure to team science in the UK.

There is increasing emphasis on 'programmes' for PhD students, and funders are demanding ever more evidence that students are acquiring core/transferable skills. For example, the MRC's latest call for Doctoral Training Partnerships (DTPs) focused on 'areas of unmet national need' such as quantitative skills.[106] In the short term, this may put more strain on academics who are tasked with delivering these programmes, as they are already dealing with the pressures of establishing research profiles (in terms of grants and publications). However, in the long run, we believe that provision of training benefits future capacity building and will empower a new generation of skilled individuals who can drive culture change by growing their research skills in multidisciplinary teams.

Box 10. Training for, and exposure to, team science

Training

- **NIHR** training initiatives for doctoral students supported in NIHR infrastructure include Biomedical Research Centres/Units (BRC/U), Collaborations for Leadership in Applied Health and Social Care and Patient Safety Translational Research Centres. A local training lead has been appointed in each of these parts of NIHR's infrastructure, to ensure that training strategies are developed, and all trainees benefit from shared expertise. Individual infrastructure centres and units are encouraged to collaborate on training. For example, the three diet and nutrition BRC/Us run joint trainee meetings and training activities. A further pilot initiative provides small bursaries to support trainee movement to other parts of the infrastructure. For example, a Nottingham hearing BRU trainee has spent several weeks training in a particular statistical technique with an expert at Leeds musculoskeletal BRU.
- **The Sanger Institute** offers a range of courses relevant to working in team science, such as: managing project teams; people management; mentoring; networking; chairing and organising team meetings; conflict resolution; communication; and assertiveness.
- Other examples include **Vitae's** Preparing for Leadership programme and the Research Team Leadership programme offered by **The Leadership Foundation for Higher Education.**

Exposure

- The **Marine Biological Laboratory Physiology Course** brings together biological and physical/computational scientists, both in the faculty and the student body, to work together on cutting-edge problems in cell physiology.[107]
- The **International Genetically Engineered Machine (iGEM) Competition** is an international competition for students interested in the field of synthetic biology. Multidisciplinary teams work throughout the summer to build genetically engineered systems.[108]
- **The Wellcome Trust four-year Interdisciplinary PhD Programme**: The four-year structure comprises intensive training together with the opportunity for short projects in all three disciplines (structural, computational and chemical biology) in the first year. Three rotation projects are chosen, and at the end of the first year students choose one project for their PhD research.[109]
- **BBSRC CASE Studentships**: BBSRC CASE studentships are collaborative training grants that provide students with research training experience, allowing bioscience graduates to undertake research, leading to a PhD, within the context of a mutually beneficial research collaboration between academic and partner organisations. All Industrial CASE research students must spend part of their time with the partner company. BBSRC now stipulates a placement period of a minimum of 3 months, and up to a maximum of 18 months.[110]
- **Industrial placements**, such as at GlaxoSmithKline, which houses over 300 industrial placement students, help to forge links with academics. Even if the internal project is terminated, they always make sure that the student still receives the training.

Recommendation 9

Focused and appropriate training in team skills should be provided.

- *Employers* should develop and provide training in team skills for researchers at all career stages. This training should be nationally recognised and cover dimensions such as leadership, management, team working, conflict resolution and unconscious bias.
- *Funders* should make career development a deliverable of grants, capturing and presenting next destinations of researchers in publicly-accessible grant reports.
- *Researchers* should be required to outline plans for governance, career development and training provision in grant applications.
- *Employers* and *funders* should train peer reviewers and panel members in how to evaluate contribution portfolios when making employment or funding decisions regarding other researchers.

“

The need for training in team working and associated skills is becoming ever more important with the increase in team science.

> “Successful team science relies on the work of researchers outside the classical ‘PI’ career path, as well as those in it. These individuals often participate in multiple team science projects, and are present at most universities.

3.8 Supporting skills specialists

3.8.1 The key role of skills specialists in team science

Successful team science relies on the work of researchers outside of the classical 'PI' career path, as well as those in it. We refer to these people here as skills specialists – individuals who provide expertise in areas such as equipment operation and project management. These individuals often participate in multiple team science projects, and are present at most universities, staffing the core facilities such as flow cytometry, mass spectrometry, genomics, imaging, electron microscopy or providing statistical analysis expertise.

There is considerable concern that these individuals do not have stable support and clear long-term career paths. This is reflected in a recent Nature article, focusing on service bioinformaticians, which stated that they *'...do not lead their own research projects, so they do not slot cleanly into an independent faculty position, despite their PhD-level training. Service-core jobs are not seen to be as prestigious as faculty posts and offer fewer opportunities for advancement and leadership'.*[111] Skills specialists often have to move institutes to develop their careers, as new positions are rarely available in-house. We consistently heard – from researchers, employers and funders – of the importance of skills specialists, and the need to support this particular cohort of researchers in their own career development, through adequate resourcing of their roles and provision of relevant career development opportunities. We also heard of the need for a clear, well-supported career path as a signpost to PhD students and postdoctoral researchers who wish to progress outside of the PI track.

3.8.2 Improving support for skills specialists

Institutions need to have well-supported skills specialist positions and career paths. We heard that research institutes are generally better positioned to do this than universities. Skills specialist positions exist in institutes with long-term core funding, but there are very few such positions in universities, which is perceived to reduce the ability to carry out long-term team science projects in universities. There is a need for an institution-wide view of the role of skills specialists within HEIs.
The precariousness of the career of skills specialists, if linked to specific project funding, was noted. There was general agreement about the need to develop stable funding mechanisms for these individuals, but we observed a spread of opinion about where the funding should come from i.e. employers or funding bodies? Good practice in supporting skills specialists needs to be identified and shared around institutions.

Recommendation 10

Clear career paths and development opportunities should be provided for researchers outside of the 'PI track' who play key roles in (and provide key competencies to) team science, such as skills specialists.

- *Employers* should actively manage skills specialists to develop their careers and support them in helping to deliver team science.
- *Researchers* should acknowledge skills specialists appropriately in research outputs, for example as authors and/or contributors on papers.

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4. Conclusions

Our investigations into team science indicate that current assessment and appraisal mechanisms are not providing due credit to excellent individuals, particularly those at the early stages of their research career. We gathered evidence from a wide cross-section of the scientific enterprise, including academia and industry, and demonstrated that change is required by scientific publishers, funders, employers and researchers. Much of this change will need to involve the international research community, and all areas of research.
Several workshops brought together key players and we are grateful to them for engaging in such a positive and enthusiastic manner. Providing a forum for discussion is a key role the Academy plays and one that we hope has catalysed the progress already being made.

In order to provide support for researchers involved in team science, we need to build better measures of recognition into infrastructures for research assessment. The research community must also champion change, challenge traditional behaviours,and train and take responsibility for ensuring that those they work with are enabled to progress their careers.

Since this team science project was suggested in 2013, the pace of technological change and its adoption by the research community means that our recommendations are achievable within the next few years. In 2013 no funder had mandated the use of individual identifiers for researchers, and ORCID was relatively new and had issued less than 40,000 IDs. Now several of the largest UK research funders, including the Wellcome Trust and the National Institute for Health Research, have mandated the use of ORCID, which now has over 1.7 million registered IDs linking to over 9.6 million outputs.

In 2013, Project CrediT had just started but 18 months on it has developed a taxonomy of contributor information being trialled at several publishers. While we recognise that barriers remain, it is now possible to document an individual's contribution to a piece of team science research. We recommend that employers and funders use that information to inform their decision-making, moving away from 'proxies', such as first or last author, and adopt a more flexible approach to apportioning credit to researchers involved in team science projects.

Funders want to support the best research but the system can be disadvantageous to those, particularly early career researchers, who play key roles in team science research but are not named on the grant. We recommend that funders consider the best way to support team science projects and their role in identifying and supporting leaders.

Finally, the Academy recognises that groups of 'early adopters' and others with an interest in challenging the scientific status quo have already been working on ways to improve recognition and credit of researchers involved in team science projects.

This report demonstrates that the issues identified affect everyone and to achieve the Academy's mission – of improving health through research – we urge the scientific community to embrace moves to ensure that team science works for the individual as well as the team.

“In 2013 no funder had mandated the use of individual identifiers for researchers, and ORCID was relatively new and had issued less than 40,000 IDs. Now several of the largest UK research funders have mandated the use of ORCID, which now has over 1.7 million registered IDs linking to over 9.6 million outputs.

Annex I: Membership of Working Group, Review Group and Secretariat

Working Group

Job titles and affiliations were correct at the time of publication. Members participated in a personal capacity and not on behalf of their affiliated organisations.

Professor Anne Ridley FMedSci (Chair)
Professor of Cell Biology, King's College London

Dr Mark Bass
Lecturer, Department of Biomedical Science, University of Sheffield

Professor Buzz Baum
Professor of Cell Biology, University College London

Professor Robert Burgoyne FMedSci
Professor of Physiology, University of Liverpool

Professor David Dunger FMedSci
Professor of Paediatrics, University of Cambridge

Professor John Fisher CBE FREng FMedSci
Deputy Vice-Chancellor, Professor of Mechanical Engineering and Director of the Institute of Medical & Biological Engineering, University of Leeds

Dr Amy Foulkes (up to May 2015)
MRC Clinical Research Training Fellow, University of Manchester

Professor Philippa Saunders FMedSci
Dean of Postgraduate Research, College of Medicine and Veterinary Medicine, University of Edinburgh

Professor Caroline Savage FMedSci
VP and Head Experimental Medicine Unit, Immuno-Inflammation Therapeutic Area, GlaxoSmithKline

Professor Eleftheria Zeggini
Group Leader, Analytical Genomics of Complex Traits, Wellcome Trust Sanger Institute

Review Group

This report was reviewed by an external panel appointed by the Council of the Academy of Medical Sciences. Reviewers were asked to consider whether the report met the terms of reference, and whether the evidence and arguments presented in the report were sound and supported the conclusions. Reviewers were not asked to endorse the report or its findings. Members participated in a personal capacity and not on behalf of their affiliated organisations.

Professor Martin Humphries FMedSci (Chair)
Vice-President and Dean, Faculty of Life Sciences, University of Manchester and Vice-President, Academy of Medical Sciences

Professor Maria Fitzgerald FMedSci
Member of the Academy of Medical Sciences Council; Professor of Developmental Neurobiology, University College London

Professor Stephen Holgate CBE FMedSci
Chair of REF2014 Main Panel A; MRC Clinical Professor of Immunopharmacology, University of Southampton

Professor Richard Horton FMedSci
Editor-in-Chief, The Lancet

Professor Ottoline Leyser CBE FRS
Chair of the Steering Group for the Nuffield Council on Bioethics 2014 report The culture of scientific research; Director of the Sainsbury Laboratory, University of Cambridge

Dr Lucia Possamai
Clinical Lecturer and Honorary SpR, Department of Hepatology, Imperial College London

Professor Chris Pugh
FMedSci Member of the Academy of Medical Sciences Council; Clinical Co-Chair of the Academy's Academic Careers Committee; Professor of Renal Medicine, University of Oxford

Dr Malcolm Skingle CBE
Director of Academic Liaison, GlaxoSmithKline

Secretariat

Dr Richard Malham
Policy Manager (Careers)

Dr Mehwaesh Islam
Policy Officer (Careers and Medical Science)

Dr Rachel Quinn
Director of Medical Science Policy

Dr Suzanne Candy (up to May 2015)
Director of Biomedical Grants and Policy

Dr Lee-Ann Coleman (from May 2015)
Interim Director of Biomedical Grants and Policy

Annex II: List of individuals and organisations engaged by the project

Job titles and affiliations are correct as at the time of engagement with the project.

Written evidence submissions

Employers
- Institute of Cancer Research
- GlaxoSmithKline
- King's College London
- London School of Economics and Political Science
- MRC Unit for Lifelong Health and Ageing, University College London
- Queen Mary University of London
- University of British Colombia
- University College London
- University of Leeds
- University of Liverpool
- University of Melbourne
- Wellcome Trust Sanger Institute

Funders
- British Heart Foundation
- Canadian Institutes of Health Research
- Higher Education Funding Council for England (including REF2014)
- Human Frontier Science Program
- International Foundation for Science
- National Health and Medical Research Council (Australia)
- National Institute for Health Research
- Research Councils UK
- Wellcome Trust

Publishers
- Elsevier
- Institute of Physics
- Wiley-Blackwell

Researchers
There were 22 individual responses: 7 female, 15 male.

Locations of respondents
European Molecular Biology Laboratory, Farr Institute of Health Informatics Research, Ghent University, Institute of Cancer Research, Institute of Psychiatry, Psychology and Neuroscience at King's College London, University College London, University of Bristol, University of Edinburgh, University of Leeds, University of Nottingham, University of Oxford.

Job titles of respondents
Assistant Professor, Chief Executive, Chief Scientific Officer, Clinical Research Fellow, Director, Group Leader, Professor, Reader, Research Associate, Research Fellow, Senior Clinical Lecturer, Senior Research Fellow, Senior Scientific Officer, Senior Statistician, Visiting Researcher.

Others
- Association of the British Pharmaceutical Industry
- British Chapter of the International Society for Magnetic Resonance in Medicine
- Norwich Clinical Trials Unit
- Open Researcher and Contributor ID (ORCID)

Local evidence gathering

The local evidence gathering engaged a total of around 78 researchers, with an approximately equal split of men and women, at the following events/institutions:

- Two discussion dinners in Scotland: Edinburgh and Dundee
- University of Bristol
- University of Cambridge
- University of Leeds
- University of Liverpool

Discussion roundtables and teleconferences

Employment discussion roundtable

Professor Frances Brodsky FMedSci Director of the Division of Biosciences at University College London

Professor Tom McLeish FRS Professor of Physics at Durham University; former Pro-Vice Chancellor (Research) at Durham University

Dr Malcolm Skingle CBE Director of Academic Liaison at GlaxoSmithKline

Professor Paul Workman FMedSci Director of the Institute of Cancer Research

Employment discussion roundtable

Dr Steve Allpress FREng Vice-President and Chief Technology Officer of Modem Software at Nvidia Corporation

Mr Andrew Clark Director of Research Planning at University College London

Professor David Hogg Pro-Vice-Chancellor for Research and Innovation at the University of Leeds

Professor Laurence Moore Director of the MRC/CSO Public Health Sciences Unit at the University of Glasgow

Mr Steven Zemke Faculty Co-ordinator at the Wellcome Trust Sanger Institute

Funding discussion roundtable

Mr Richard Carter Deputy Director, Sponsorship, Performance and Workforce, Department of Health

Dr Anne-Marie Coriat Head of Research Careers, Wellcome Trust, formerly Chair of the Research Councils UK Research Group and Director of Capacity, Skills and Infrastructure at the Medical Research Council

Professor David Delpy CBE FRS FREng FMedSci Former Chief Executive of the Engineering and Physical Sciences Research Council (EPSRC)

Professor Keith Gull CBE FRS FMedSci Deputy Chair of the Wellcome Trust Pathogen Biology and Disease Transmission Expert Review Group and Professor of Molecular Microbiology at the University of Oxford

Dr Steven Hill Head of Research Policy at the Higher Education Funding Council for England (HEFCE)

Professor Stephen Holgate CBE FMedSci Chair of REF2014 Main Panel A and MRC Clinical Professor of Immunopharmacology at the University of Southampton

Ms Jan Juillerat Executive Director for People & Development at the Biotechnology and Biological Sciences Research Council (BBSRC)

Professor Tom McLeish FRS Professor of Physics at Durham University; former Pro-Vice Chancellor (Research) at Durham University

Dr David Scott Director of Discovery Research and Centres, Cancer Research UK

Professor Paul Stewart FMedSci Chair of the British Heart Foundation Chairs and Programme Grants Committee and Dean of Medicine at the University of Leeds

Dr John Williams Head of Science Strategy, Performance & Impact Science at the Wellcome Trust

Publishing discussion roundtable

Dr Liz Allen Co-Chair of Project CRediT, formerly Head of Evaluation, Wellcome Trust

Dr Helen Atkins Director of Publishing Services at the Public Library of Science (PLOS); formerly Acting Publisher, PLOS

Dr Ritu Dhand Nature Editorial Director at Nature Publishing Group

Deborah Dixon Vice-President and Global Publishing Director of Health Sciences at John Wiley & Sons

Dr Holly Falk-Krzesinski Vice-President of Global Academic & Research Relations at Elsevier

Dr Trish Groves Head of Research and Deputy Editor at the British Medical Journal

Dr Laurel Haak Chief Executive of ORCID

Dr Andrew Sugden Deputy Editor and International Managing Editor of Science at the American Association for the Advancement of Science (AAAS)

Researcher workshop

Mr Martin Baker PhD student, Babraham Institute

Mr Matthew Balmforth PhD student, University of Leeds

Dr Matthew Care Postdoctoral Fellow, University of Leeds

Dr Rachel Clough NIHR Academic Clinical Lecturer, King's College London

Dr Ed Conley Chief Scientific Officer, Farr Institute

Professor Ton Coolen Professor of Applied Mathematics, King's College London

Dr Alastair Darby Lecturer, University of Liverpool

Dr Felix Day Career Development Fellow, University of Cambridge

Dr Ben Fairfax Clinical Research Fellow, Wellcome Trust Centre for Human Genetics, University of Oxford

Dr Tim Felton Clinical Research Fellow, University of Manchester

Dr Peter Foley Clinical PhD student, University of Edinburgh

Professor Tom Freeman Group Leader, Systems Immunology, University of Edinburgh

Dr Alexandra Gampel Research Fellow, University of Bristol

Dr Melissa Gladstone Senior Clinical Lecturer, University of Liverpool

Dr Derek Groen Lecturer in Simulation and Modelling, Brunel University; Emeritus Research Fellow, 2020 Science

Ms Laura Huckins PhD student, Wellcome Trust Sanger Institute

Dr Wendy Jones Clinical PhD student, Wellcome Trust Sanger Institute

Professor Benedikt Kessler Professor of Biochemistry and Mass Spectrometry, University of Oxford

Mrs Dee Knipe PhD student, University of Bristol

Professor Cathryn Lewis Professor of Genetic Epidemiology and Statistics, Institute of Psychiatry, King's College London

Mr Dianbo Liu PhD student, University of Dundee

Dr Andrew McKechanie Clinical Research Fellow, University of Edinburgh

Professor Helen McShane Professor of Vaccinology, Wellcome Senior Clinical Fellow, University of Oxford

Professor Jane Nixon Professor of Tissue Viability and Clinical Trials Research, University of Leeds

Dr Lucia Possamai Clinical Lecturer and Honorary SpR, Department of Hepatology, Imperial College London

Dr Thomas Rendall Lecturer, University of Bristol

Dr Emily Sena Research Fellow, University of Edinburgh

Dr Ioanna Tzoulaki Senior Lecturer, Imperial College London

September workshop

Dr Liz Allen Co-Chair of Project CRediT, formerly Head of Evaluation, Wellcome Trust

Dr Helen Atkins Director of Publishing Services at the Public Library of Science (PLOS); formerly Acting Publisher, PLOS

Dr Guntram Bauer Director of Scientific Affairs & Communications, Human Frontier Science Program (HFSP)

Dr Theo Bloom Executive editor, BMJ

Dr Annette Bramley Lead, Healthcare Technologies, Engineering and Physical Sciences Research Council (EPSRC)

Mr Richard Carter Deputy Director, Sponsorship, Performance and Workforce, Department of Health

Professor Mark Caulfield FMedSci Chief Scientist, Genomics England

Professor David Collingridge Editor-in-Chief, The Lancet Oncology; representing Elsevier

Dr Anne-Marie Coriat Head of Research Careers, Wellcome Trust, formerly Chair of the Research Councils UK Research Group and Director of Capacity, Skills and Infrastructure at the Medical Research Council

Professor Christopher Day FMedSci Chair of the Clinical Medicine Sub-panel for the 2014 Research Excellence Framework (REF); Pro-Vice-Chancellor for the Faculty of Medical Sciences, Newcastle University

Professor David Delpy CBE FRS FREng FMedSci Former Chief Executive of the Engineering and Physical Sciences Research Council (EPSRC)

Dr Ben Fairfax Clinical Research Fellow, Wellcome Trust Centre for Human Genetics, University of Oxford

Mr Chris Graf Vice-Chair, Committee on Publication Ethics (COPE)

Dr Derek Groen Lecturer in Simulation and Modelling, Brunel University; Emeritus Research Fellow, 2020 Science

Dr Steven Hill Head of Research Policy, Higher Education Funding Council for England (HEFCE)

Professor Jacqueline Hunter CBE FMedSci Chief Executive, Biotechnology and Biological Sciences Research Council (BBSRC)

Dr Astrid James Deputy Editor, The Lancet

Dr Chonnettia Jones Head of Science Integration – Structures, Wellcome Trust

Ms Sarah Jones Head of Education and Academic Liaison, Association of the British Pharmaceutical Industry

Professor Benedikt Kessler Professor of Biochemistry and Mass Spectrometry, University of Oxford

Ms Maria Khan Editorial Director, Health Sciences, Wiley-Blackwell

Professor Cathryn Lewis Professor of Genetic Epidemiology and Statistics, Institute of Psychiatry, King's College London

Dr Natasha McCarthy Head of Policy, the British Academy

Professor Anne O'Garra FRS FMedSci Representing the Royal Society; Associate Research Director (Group Leader Development), Francis Crick Institute

Professor Guy Orpen Chair of GW4 Board; Deputy Vice-Chancellor, University of Bristol

Mr Ed Pentz ORCID Board Member; Executive Director of CrossRef

Dr Stefan Platz Vice-President for Drug Safety and Metabolism, AstraZeneca

Dr Danielle Preedy Assistant Director for the Efficacy and Mechanism Evaluation Programme, National Institute for Health Research (NIHR)

Dr Joanna Robinson Head of Capacity and Skills, Medical Research Council (MRC)

Dr Emily Sena Research Fellow, University of Edinburgh

Dr Eva Sharpe Policy Manager, Institute of Cancer Research

Professor James Smith FRS FMedSci Director of Research, Francis Crick Institute

Dr Andrew Sugden Deputy Editor and International Managing Editor, Science, the American Association for the Advancement of Science (AAAS)

Dr Peter Thompson Assistant Director, Personal Awards Team, National Institute for Health Research (NIHR)

Ms Anna Wilkinson Programme Officer, Nuffield Council on Bioethics

Professor James Wilsdon Chair of the Independent Higher Education Funding Council for England (HEFCE) Review on the Role of Metrics in Research Assessment; Professor of Democracy Science & Technology Policy Research (SPRU), Sussex University

One-off meetings with other individuals/groups

Professor Richard Horton FMedSci Editor-in-Chief, The Lancet

Dr Shane Legg Co-Founder, Google DeepMind

Dr Beverley Sherbon Evaluation Programme Manager, Medical Research Council

Medical Academic Staff Committee British Medical Association

Standing Committee on Assessments Canadian Academy of Health Sciences

Meetings attended

Project CRediT workshop, Capital Hilton, Washington D.C., US, December 2014

Evaluating interdisciplinary research workshop, Durham University, UK, March 2015

Research Councils UK (RCUK) Policy workshop on interdisciplinary research, 1 Kemble Street, UK, April 2015

Our scholarly recognition system doesn't still work panel event Science of Team Science Conference, National Institutes of Health, US, June 2015

Nuffield Bioethics workshop on research culture Aston University, UK, July 2015

Annex III: Balance between team science and single PI funding

To inform our understanding of trends in team science in the UK, we consulted with a number of research funders to collect retrospective information on collaborative or multidisciplinary grant proposals. Our aim was to integrate data from several funders to determine trends in team size and whether it correlated with application success and grant size.

However, several issues emerged when we attempted to combine the data and impacted on the ability to complete any meaningful analysis:

- The ‘decision years’ for different funders do not align. For example, some funders use calendar years while others align their allocations with financial years.
- The retrospective time frame of four to five years may be too short to track significant changes in team science behaviour.
- Pooling the data from different funders helps to increase the statistical power, but data from larger funding bodies can mask contributions from smaller charities and trends in their team science culture may be lost.
- The different eligibility requirements of funders for including applicants may not enable true comparison of team science participants.

Analysing the data from funders to better understand the drivers for team science remains an interesting avenue to explore. Improved access to Research Council UK’s funding data through Gateway to Research (GtR) offers possibilities for investigating how funding impacts on team science and the Gateway for Higher Education (G4HE) beta service provides information about collaborations derived from the GtR data. Many charities also contribute their funding data to the Association of Medical Research Charities. Some of the areas to explore further include:

- The effect of changes in total funding portfolios over time, in terms of the amount awarded to teams versus individuals.
- The average amounts (real and % of award) funders provide for the support costs of team science projects such as meetings, project management and co-ordination.
- The length of team science awards and the impact of shortening/lengthening this time.
- Whether portable Fellowships can be embedded in team science grant applications.
- How funders support the career development of participants within team science grants.

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