Executive Summary

The rise in antimicrobial resistance (AMR) is a global problem that threatens human, animal and environmental health and wellbeing. Research plays a vital role in preventing the spread of disease, protecting the antibiotics we currently have, and promoting new therapies and interventions. The UK is a leader in AMR research and it is important to maintain momentum and drive innovation by ensuring the appropriate capacity and skills are in place.

Through this review of capacity and skills, the AMR Funders Forum has identified a number of areas of concern that could impact the UK’s research productivity if not addressed: data science, interdisciplinarity and veterinary/clinical microbiology. Data science and interdisciplinary science have been identified in other capacity and skills reviews in recent years, and part of the issue is in attracting those from other disciplines to work on the challenge of AMR.

Efforts to increase capacity in data science and interdisciplinary research are already underway through the provision of more PhD and fellowship places in the UK. Incentivisation to attract researchers from non-biomedical fields, and networking opportunities to bring researchers from disparate disciplines together, will help to increase capacity and drive innovation to tackle AMR. These efforts are important both here in the UK and globally, as resistant microbes do not respect international boundaries.

1. Introduction

The discovery, development and use of antibiotics to treat disease was arguably one of the greatest achievements of the 20th century. However, less than 80 years on, antimicrobial resistance (AMR) threatens to undermine this great achievement, putting up to 10 million lives a year at risk by 2050 if solutions are not found. Modern clinical procedures, such as surgery or chemotherapy, will be more of a risk without effective antibiotics to fight infection and disease. Farmers also rely on antibiotics to safeguard their livestock and crops, while little is known about the impact of AMR on the environment.

What is AMR? The development of resistance is a natural phenomenon that arises through genetic mutation and the transfer of mobile genetic elements. However, the inappropriate use of antibiotics selects for resistant strains of bacteria at an artificially high rate. Better disease prevention, protection of the antibiotics we currently have through better antibiotic stewardship, and the promotion of new therapies, including antibiotics, are all required to tackle the growing threat of drug-resistant infections. AMR is a global problem which needs to be addressed with urgency.

The World Health Organisation (WHO) implemented a global action plan on AMR in 2015, as the development and spread of resistance occurs irrespective of national boundaries. The growing threat of AMR has been recognised in the UK for many years, however publication of the Chief Medical Officer’s (CMO) report in 2013 was the impetus for a UK-wide mobilisation of government organisations to tackle the problem.

In the UK, the AMR Funders Forum (AMRFF) brings together a range of key public sector organisations and charities to ensure a coordinated approach to tackling AMR both at home.
and abroad. The challenge of AMR is very broad, covering basic discovery research through to implementation. To ensure a continuous pipeline from basic discovery research through to the implementation of new tools, we need the appropriate capacity and skills base in the UK. To this end, the AMRFF conducted a survey of capacity and skills for AMR research. Survey results were supplemented with information gleaned from recent training reviews and discussions held in a variety of settings, including workshops and meetings with stakeholders.

2. The Survey

A strong skills base is essential for the UK to remain at the forefront of AMR research. In 2016, AMRFF members agreed to review the current landscape of UK AMR research capacity to identify skills gaps. This would allow us to prioritise activities to ensure a coordinated and effective research effort to tackle the challenge of AMR.

A ‘capacity and skills’ working group of the Funders Forum initiated the review and set up a survey in consultation with AMRFF members. The survey questions were designed to capture diverse aspects of career development in AMR, including key skill sets required to conduct AMR research, and any gaps or challenges that need to be addressed. A copy of the survey questionnaire and collated responses is provided in Annex 1.

To better understand the breadth of the skill set required to combat AMR we invited a wide range of individuals working in different sectors to respond to our survey. The survey was completed by 363 individuals, which compares favourably with other recent capacity and training reviews. Academics provided the majority of responses (79%). Additional responses came from the hospital sector (10%), government (5%) and industry (4%) with ‘Other’ coming from the charities, retirees or other branches of the NHS (2%). Respondents were asked to identify themselves with one research discipline (survey question 2). The majority associated themselves with biological or clinical sciences (over 60% combined). Responses from other disciplines varied from 9% for social sciences down to 1% for arts and humanities (Figure 1). This may reflect the different levels of engagement of the community with the AMR challenge.

Figure 1: Research discipline of AMR survey respondents

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4 Survey working group: MRC/DTSL (Sarah Harding), Innovate UK (Penny Wilson), NIHR (Peter Thompson), VMD (Katherine Grace).

5 British Society of Immunology Careers Report 2017 (651 PhD thesis authors); Cross funder review of early career academics, 2015 (36% response rate with 437 responses)
The research areas represented by the respondents was captured in question 3 of the survey (see Annex 1). The response to this question was by free text although suggested categories were supplied, and these have been used to group responses (see Figure 2). Some respondents gave multiple answers; therapeutics was cited more frequently in association with diagnostics than in association with interventions, and surveillance was often cited in association with transmission. Some areas of research were cited less frequently, probably reflecting respondents’ broader research discipline. These research areas have been grouped together under ‘Other’, although this is not meant to denigrate their importance.

![Research Area of Respondent](image)

**Figure 2**: Research areas of survey respondents. ‘Other’ includes: epidemiology, evolution, history and sociology

The broad spectrum of research expertise, from basic discovery research through to the development of interventions to combat AMR is exemplified with an interdisciplinary research project funded to develop a point of care diagnostic device for use by health practitioners to distinguish between viral and bacterial infections and thereby aid their decision to treat infections with antibiotics. Professor Christoph Walti and colleagues from the University of Leeds assembled an interdisciplinary consortium including engineers, biologists and clinicians with expertise in nanotechnology, protein engineering, biophysical tools development, medical microbiology, computational fluid dynamics, biostatistics, *in vitro* diagnostics, and clinical evaluation

### 3. Skills required to conduct AMR research

Survey respondents identified over 250 different specific skills associated with their research\(^7\), a testament to the breadth of skills which is being brought to bear on the problem in the UK. We also asked respondents to identify skills gaps that may impact on the delivery of continued excellence in AMR research (Figure 3). Two key gaps were identified: data science and interdisciplinary research.

These findings are in line with a 2015 review of biomedical and bioscience research skills which recorded a total of 242 responses\(^8\). Both interdisciplinarity and maths/statistics/...
computation were listed in the top 5 vulnerable skills areas, especially at the postgraduate and postdoctoral levels.

![Skills Gaps](chart.png)

**Figure 3:** Skills gaps identified by survey respondents

### 3.1. Data Science

By far the most often-cited gap in skills and the ability to progress research to combat AMR was data science, representing one-third of the responses received. Included in this category were data handling and analysis, computation, modelling and bioinformatics skills. The emphasis on quantitative versus qualitative skills varied depending on the discipline of the survey respondent. For example, those working in the social and clinical sciences were much more likely to list qualitative skills as important for their research than those working in the biological sciences.

Why is training in data science so important for driving research excellence to combat AMR? Traditional approaches to pathogen identification and the evaluation of antibiotic resistance involve time-consuming bacterial culture and susceptibility testing. Increasingly, data heavy approaches are being used to combat AMR, as illustrated in the following examples of surveillance and outbreak investigation.

Professor Sharon Peacock and colleagues were awarded funding for a grant entitled ‘Development, evaluation and translation of next-generation sequencing tools to track MRSA transmission pathways’ from the UK Clinical Research Collaboration (UKCRC) Translational Infection Research Initiative. A database of whole genome sequences for *Staphylococcus aureus* bacterial samples was published and made available on the European Nucleotide Archive (ENA) in 2016. The bacteria were collected from various locations in the UK. It has already proved to be a valuable resource for surveillance and outbreak investigation of MRSA in the UK and Ireland, and will continue to be an important resource for future investigation.

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9 Seven organisations are involved in funding the UKCRC Translational Infection Research Initiative, including the BBSRC, MRC, the Wellcome Trust, NIHR and the devolved administrations in Northern Ireland, Scotland and Wales.


11 Citations listed in PubMed for PMID 26672018:
Professor Tim Walsh and colleagues were awarded a grant entitled ‘Determining the clinical and environmental impact, burden and cost of extensively drug resistant Enterobacteriaceae in China (DETER-XDRE-CHINA)’ through the Newton Fund\(^\text{12}\). The large-scale collection and analysis of data resulted in internationally recognised publications\(^\text{13}\) and a ban on the use of colistin as an animal feed additive\(^\text{14}\).

The PASS project – preserving antibiotics through safe stewardship – is an example of the use electronic patient records from a range of health settings to understand how healthcare staff are using antibiotics in general practice, hospitals and nursing homes for the elderly. Interviews will be conducted to get a deeper understanding of what influences decisions about antibiotic use. The science of behaviour change will allow Professor Andrew Hayward and colleagues to understand the human behaviour of antibiotic use and how best to change it.

Responses from the more translational arms of research capacity (industry, hospitals and government) all cited data science as a key skill for future research delivery, often in conjunction with data platforms and clinical decision-making tools. In addition, genetics was also noted as a key skill for these groups.

### 3.2. Interdisciplinarity

Interdisciplinary research was the second most frequently cited response to our request for skills gaps for conducting research to combat AMR (\textit{Figure 2}). This response came predominantly from researchers working in an academic environment.

The key reasons cited for the perceived gap in interdisciplinary research were:

- lack of understanding of the potential value of less-familiar disciplines
- limited personnel with the required skills
- interdisciplinary skills aren’t applied to AMR research
- lack of access to necessary facilities and equipment

Difficulties in recruiting and retaining staff with the appropriate interdisciplinary skills was cited by 20% of respondents as current and future barriers to research excellence, equivalent to the number of responses citing a lack of appropriate funding as the biggest barrier to progressing their research. Encouraging more engagement from researchers in the economics, agriculture, arts and humanities, environment and engineering fields was also important. Responses from these disciplines were under-represented in the survey (see \textit{Figure 1}), highlighting a lack of engagement in AMR research in these fields.

Barriers to conducting interdisciplinary research were less frequently cited by those working in industry, hospitals or government facilities. The disparity between responses from academic researchers and those producing products and services to combat AMR may reflect perceived gaps in cross-disciplinary research funding through the research councils by academics, or a pragmatic approach to outcome delivery by those working in more translational settings. One example of a translational research funding approach which has attracted global interest from interdisciplinary groups is the Longitude Prize\(^\text{15}\).

\[^{12}\text{http://gtr.rcuk.ac.uk/projects?ref=MR%2FP007295%2F1}\]
\[^{14}\text{Walsh TR and Wu Y, China bans colistin as a feed additive for animals, \textit{The Lancet Infectious Diseases} (2016).}\]
\[^{15}\text{The Longitude Prize is managed by Nesta on behalf of Innovate UK: \textit{https://longitudeprize.org/about-us}}\]
The UK government established the Longitude Prize in 2014, to tackle growing levels of antimicrobial resistance. The challenge is to invent a diagnostic test for bacterial infections that is fast, accurate, affordable, safe, easy-to-use, scalable and connected, allowing health professionals worldwide to administer the right antibiotics at the right time and thereby decrease inappropriate use. Three years and 250 registered teams later, many of the development awards, small awards to pump prime promising avenues of research, use data driven approaches and interdisciplinary teams to develop a diagnostic capable of winning the Prize.

3.3. What can be done to address the gaps?
As part of the survey, respondents were asked if there are barriers which make conducting AMR research difficult, what those barriers are, and what could be done to address them (see questions 8-10, Annex 1). Perhaps unsurprisingly funding was the most frequently cited barrier to conducting AMR research. More opportunities to develop skills and more training in specific areas were also noted as ways in which barriers to research could be addressed, as well as new funding/ business models to attract industry, and better communication/ promotion of existing opportunities.

4. Other inputs
There have been other sources of information on capacity and skills for conducting AMR research, including other reviews, workshops and ad hoc meetings with various stakeholders. In July 2017, the AMR cross-council initiative held a workshop for award holders. A session was held exploring skills and capacity challenges of conducting AMR research. Feedback from this session supported the survey findings on the need for more researchers with informatics, data and modelling skills and the necessity to help bring existing expertise together to develop and reward interdisciplinary working. In addition, and perhaps reflecting the breadth of research represented at the workshop, needs in health/ business economics, building design, civil engineering and law were also highlighted.

Further discussion with BBSRC specialist groups, and MRC boards, centres and units, highlighted shortages of veterinary and clinical microbiologists. Current leadership in these fields is reaching retirement and recruitment is proving challenging.

5. Addressing the Gaps
Both computational skills and the need for more interdisciplinary working have been highlighted in previous skills reviews. Generic gaps in interdisciplinary skills and data science skills have been addressed to some extent through schemes such as the Skills Development Fellowships at MRC16 and the Strategic Training Awards for Research Skills (STARS) at BBSRC17. One of the ambitions for the new Health Data Research UK (HDR UK) institute is to develop capacity within biomedical informatics18. ESRC has committed to introducing new Centres for Doctoral Training (CDTs) in focused thematic interdisciplinary research areas19, the first two of which have been funded combining training in social sciences with the analytical capabilities to handle high-dimensional data sets. EPSRC fellowships include a number of priority areas which are of relevance to the AMR field20 while

16MRC Skills Development Fellowships https://www.mrc.ac.uk/skills-careers/fellowships/skills-development-fellowships/
17 BBSRC STARS programme https://www.bbsrc.ac.uk/funding/filter/stars/
18 HDR UK https://www.mrc.ac.uk/about/institutes-units-centres/uk-institute-for-health-and-biomedical-informatics-research/
20 EPSRC Fellowship priority areas https://www.epsrc.ac.uk/skills/fellows/areas/priorityareas/
NERC supports interdisciplinary skills through their National Productivity Investment Fund allocation\textsuperscript{21}.

In the specific field of AMR, the Medical Research Foundation is providing over £2.5m for 18 PhD studentships across 16 universities for an Antimicrobial Resistance PhD Training Programme\textsuperscript{22}, to help build a cadre of interdisciplinary trained researchers. Existing cross-Council investments in AMR provide the platform for delivery of these studentships. The Wellcome Trust funds a Doctoral Training Centre in Antimicrobials and AMR\textsuperscript{23} which is also designed to provide multidisciplinary training specific to AMR. The EPSRC supported 11 interdisciplinary collaborations focussed on the challenge of AMR through the Bridging the Gaps between the Engineering and Physical Sciences and AMR programme\textsuperscript{24}.

These programmes all provide a good foundation for increased skills development in both data science and interdisciplinarity, however the community highlighted additional activities which would facilitate better coordination of activities and interdisciplinary working.

6. Conclusions and recommendations
The UK AMR research community is open and innovative, taking an active approach to collaboration and the development of new technology. However, there are opportunities for stakeholders to strengthen research capacity and remove barriers to improve AMR research outputs and impacts.

To ensure continued excellence and momentum in research to combat AMR the following gaps in current and future research capacity need to be filled:

- Data science - including data collection, handling and analysis, mathematics, computation and modelling, programming, and bioinformatics.
- Interdisciplinary skills – which would allow researchers to apply mathematics and engineering solutions to biological problems, and use frameworks to ensure their research outputs will deliver social, economic and clinical impact.
- Microbiology – to ensure expertise in animal and human clinical microbiology, and basic discovery science.

Stakeholders, including the membership of the AMRFF, can also play their part to increase research capacity and interdisciplinarity of research by:

- Ensuring continued training opportunities to fill current and future gaps in capacity;
- Providing opportunities for researchers at all career stages to establish and maintain interdisciplinary collaborations by facilitating networking activities;
- Communicating training, networking and funding opportunities as broadly as possible.

\textsuperscript{21} NERC Industrial Innovation Fellowships \url{http://www.nerc.ac.uk/funding/available/fellowships/iif/}
\textsuperscript{22} MRF National PhD Training Programme in AMR \url{https://www.medicalresearchfoundation.org.uk/our-research/national-phd-training-programme-in-amr/}
\textsuperscript{23} Wellcome Trust DTC in antimiucroicals and AMR \url{https://www.birmingham.ac.uk/schools/mds-graduate-school/wellcome-aamr/programme/programme.aspx}
\textsuperscript{24} EPSRC Bridging the Gaps – EPS and AMR awards \url{http://gow.epsrc.ac.uk/NGBOViewPanelROL.aspx?PanelId=1-2H6XUI&RankingListId=1-2H6XW7}