Interdisciplinary research in epidemic preparedness and response

Workshop report

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Opinions expressed in this report do not necessarily represent the views of all participants at the event, the Academy of Medical Sciences, InterAcademy Partnership for Health, or its Fellows.

All web references were accessed in February 2020.

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Preface

During the 21st century, the world has experienced multiple devastating epidemics of Ebola, Zika, Yellow Fever, Lassa fever, Nipah virus and many other infectious diseases. Epidemics are defined by the complex interactions between microbes, people, animals and ecosystems, and factors such as increased global mobility, population density and climate change are contributing to the rise of epidemics caused by emerging and re-emerging diseases. As well as their health impacts, epidemics cause huge social disruption and have enormous economic consequences for affected countries.

Infectious disease outbreaks are seemingly inevitable. However, their impact can be mitigated through better preparedness and more effective responses. Research has a key role to play in both preparedness and intervention. Furthermore, given the multiplicity of biological, social, cultural and environmental factors affecting the spread of infections, many different kinds of research – biomedical, social and environmental sciences – all have important contributions to make. Work across disciplines, however, is often not well integrated.

To address this need for interdisciplinary research, the Academy of Medical Sciences (AMS), the InterAcademy Partnership (IAP) and the Medical Research Council (MRC) convened a two-day workshop in London in October 2019 funded by the AMS, through the Global Challenges Research Fund (GCRF), and the MRC. The workshop set out to explore the evidence required for effective epidemic preparedness, prevention and response, particularly in low- and middle-income countries, and how interdisciplinary research can best be facilitated to meet these evidence needs.

The organisers and a steering committee chaired by Professor Jimmy Whitworth FMedSci, London School of Hygiene and Tropical Medicine, UK, and Professor Rajae El Aouad, Hassan II Academy of Science and Technology, Morocco, developed the workshop programme. This report provides a summary of the key themes to emerge during the workshop. It reflects the views expressed by participants at the workshop and does not necessarily represent the views of all participants, all members of the steering committee, the AMS, the IAP or the MRC.

Executive summary

Despite enormous progress in the prevention and treatment of infectious diseases during the 20th century, infectious disease epidemics continue to affect the world. Transmission of pathogens from animals to humans poses a particular risk, as seen in devastating recent Ebola, severe acute respiratory syndrome (SARS) and new coronavirus outbreaks (SARS-CoV-2). Furthermore, climate change, urbanisation, extensive population mobility and intercontinental air travel have created opportunities for the rapid global spread of emerging and re-emerging pathogens.

These threats have focused attention on global health security and the urgent need for global and national preparedness, outbreak prevention, and coordinated responses to extinguish new outbreaks as rapidly as possible. Effective preparedness covers multiple areas, spanning infectious disease surveillance, infection prevention and control within the community and health facilities, population protection through vaccination, outbreak investigation, and planning of rapid coordinated responses to emergent epidemics. Furthermore, effective preparedness requires a thorough understanding of the ecology of infectious diseases, the impacts of factors such as changing land use and mobility patterns, the effects of urbanisation and climate change, as well as cultural contexts.

Research has a key role to play in both epidemic preparedness and response, including the development and clinical evaluation of new interventions (drugs, vaccines and diagnostics), understanding transmission, and assessing the effectiveness of responses. Infectious disease transmission and control is a complex area, affected by multiple biological, environmental, behavioural and social factors. Understanding how all these factors interact calls for input from researchers across multiple disciplines, including laboratory sciences, epidemiology, engineering, clinical research, veterinary science, ecology, climate science, health systems research, health economics and behavioural sciences.

All these domains of research have important contributions to make, to identify key factors in the emergence and spread of infectious disease and ways in which the spread of infections can best be controlled. However, the efforts of researchers in different disciplines are not always fully integrated, and significant obstacles exist to productive interdisciplinary research.

Participants at a two-day international workshop organised by the Academy of Medical Sciences, the InterAcademy Partnership and the Medical Research Council (held in London, October 2019) identified a range of key multi- and interdisciplinary research priorities in support of public health goals across four key phases – ‘prepare’, ‘prevent’, ‘respond’ and ‘recover’. Much attention is given to the development of new drugs, vaccines and diagnostics to control outbreaks. However, environmental factors, human behaviour, and social and political contexts are all powerful influences on the emergence, transmission and spread of infectious disease, highlighting the potential of wider public health interventions to control disease. Interdisciplinary research is therefore key to ensure effective:

- **Knowledge generation:** Understanding the full range of physiological, cultural, environmental and socioeconomic factors affecting infectious disease emergence/re-emergence and transmission.
- **Intervention development:** Developing and evaluating multifaceted evidence-based public health interventions to prevent infection and interrupt transmission.
- **Modelling:** Developing multidimensional models for risk assessment, comparing the impact of intervention strategies, and assessing their cost-effectiveness.
- **Evaluation:** Informing and evaluating preparedness plans, prevention activities and outbreak responses.

A key need for interdisciplinary research is to understand the factors underpinning the behaviour and decision-making of groups, such as communities at risk or affected by outbreaks, healthcare workers and public health officials, and political leaders and policymakers with responsibility for preparedness and responses. In addition, as the climate emergency is likely to increase the risk of infectious disease outbreaks, multi- and interdisciplinary research on outbreaks needs to be integrated with wider climate change preparedness activities.

Workshop participants also identified critical obstacles to multi- and interdisciplinary research and ways they might be overcome. Among the key facilitators highlighted were:

- **Building and sustaining partnerships:** Establishing interdisciplinary research partnerships in advance of epidemics and sustaining them.
- **Community engagement:** Developing strong relationships with communities, building trust, and involving communities in agenda setting, intervention development and research activities.
- **Capacity building:** Developing in-country multi- and interdisciplinary research capacity.
- **Funder engagement:** Ensuring that funders prioritise and develop appropriate mechanisms to support multi- and interdisciplinary research for epidemic preparedness and response.

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Introduction

The 20th century saw huge progress made in the battle against infectious disease. Although scientific advances, clean water and better hygiene have dramatically reduced the death toll from infectious disease, humans remain vulnerable to the emergence of new infections, particularly those acquired from animal sources, and to the re-emergence of old foes. In addition, basic sanitation, and access to vaccines and therapeutics is not universal; many populations, particularly in low- and middle- income countries (LMICs), still lack basic amenities and healthcare, and are also often more adversely affected by extreme climate events, which can themselves be detrimental to disease control and sanitation, putting communities at increased risk. As a result, within the past 20 years, severe acute respiratory syndrome (SARS), Middle East respiratory syndrome (MERS), Zika, Ebola and many other pathogens have all caused documented outbreaks (Figure 1).

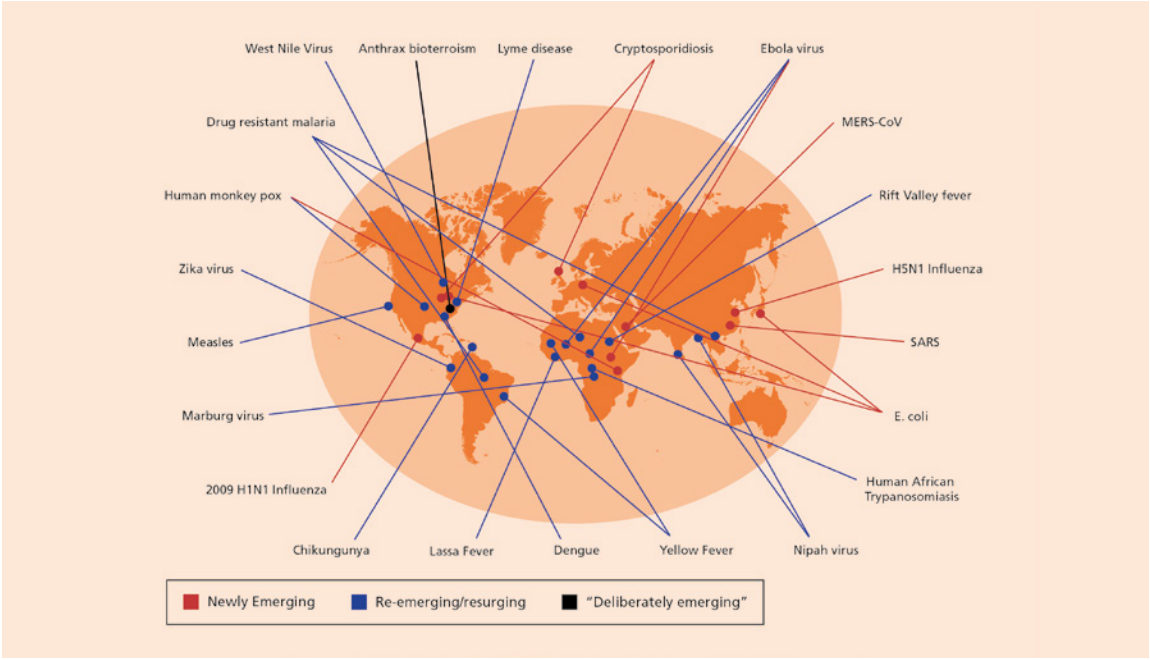

Figure 1: Examples of emerging and re-emerging disease outbreaks. Adapted from Paules CI *et al.* (2017). *What Recent History Has Taught Us About Responding to Emerging Infectious Disease Threats.* Ann Intern Med 167(**11**), 805-811.

LMICs are particularly vulnerable to emerging infections. In many LMICs, animals and humans live in close proximity, creating opportunities for cross-species transmission of pathogens (so-called 'spillover'). Health systems and surveillance may be weak, creating delays in the detection, confirmation and treatment of new infections. Cultural practices, such as burial arrangements, may also present opportunities for infections to spread through communities. An understanding of and sensitivity to local practices can be critical for building trust with communities. During the Ebola outbreak in Liberia, for example, western relief workers initially used black body bags for burials. However, white is the traditional colour of mourning in Liberia, leading to discontent that was resolved by the introduction of white body bags.

Extensive population mobility, including migration and urbanisation, creates opportunities for rapid transmission of infectious diseases. Natural disasters, environmental degradation and climate change are fundamentally altering ecosystems and human lives in ways that are significantly altering the risk of exposure to pathogens.

In addition, civil conflict and community mistrust may hinder attempts to control disease outbreaks. Political leaders may also be reluctant to be open about outbreaks, because of fears about the impact on the economy including trade and tourism as well as on national reputation.

The West Africa Ebola outbreak of 2014–16, which claimed the lives of 11,000 people directly and at least as many indirectly, was a pivotal moment in global health security.[1] It shone a spotlight on weaknesses in preparedness of countries in this region, already challenged by significant diseases like tuberculosis and measles that have not received the same level of global attention as other regions. The outbreak was eventually brought under control, but not without significant loss of life and economic impact on the three countries affected (Guinea, Liberia and Sierra Leone). The outbreak raised questions about how well prepared countries and the global community were to respond to outbreaks, and triggered an increased emphasis on efforts to coordinate outbreak response and on epidemic preparedness, including incorporation of research.

International Health Regulations (2005) provide a global framework for international cooperation to detect, prevent and respond to infectious disease outbreaks, with external evaluations informing the development of national preparedness plans.[2] Since the West Africa Ebola outbreak, the global research community has established structures such as the WHO Global Coordinating Mechanism for Research and Development (R&D) in epidemics, and the R&D Blueprint, to improve coordination of research activities in advance of and during outbreaks, intended to accelerate the development of diagnostics, therapeutics and vaccines.[3] The Coalition for Epidemic Preparedness and Innovation (CEPI) has also been created to accelerate the development of new vaccines against priority pathogens. In addition, a number of networks have been established to promote regional and North–South collaboration to enhance preparedness for research during outbreaks. These include networks such as Sonar-Global which aim to link social sciences researchers with interests in infectious disease and outbreak control. However, an analysis of outputs linked to the 2014–16 West Africa Ebola outbreak suggested that epidemiological and social research, for example, were generally not well integrated.[4]

Even so, in its first annual report, A World at Risk, published in September 2019, the Global Preparedness Monitoring Board concluded that the world is poorly prepared to respond to new global threats.[5] It suggested that global actions were still dominated by responses to outbreaks, with too little investment in preparedness. It also noted that there were multiple different aspects of preparedness, including governance and coordination, country preparedness, research and development, community engagement and trust, and resourcing.

On the research side, this complexity is reflected in the wide range of disciplines that are relevant to epidemic preparedness and response. These include the 'discovery' sciences needed to understand pathogens and host responses, as well as transmission, e.g. via vectors from host reservoirs. Translational R&D is focused on the development and evaluation of new diagnostics, vaccines and pharmaceuticals. In addition, the ecological and social contexts of research require different types of expertise, while veterinary research is important for understanding the human–animal interface. There is also a need to consider the appropriate governance of research, including ethical review and regulatory oversight, as well as the global and national political context that drives preparedness and response decision-making.[6] [7]

1. Wilhelm JA, Helleringer S. (2019) *Utilization of non-Ebola health care services during Ebola outbreaks: a systematic review and meta-analysis JGlob Health.*
2. World Health Organization (2005). *International Health regulations- third edition.* Available at: https://www.who.int/ihr/publications/9789241580496/en/
3. World Health Organization (2016). *An R&D Blueprint for action to prevent epidemics.* Available at: https://www.who.int/blueprint/en/
4. Abramowitz SA, et al. (2018). *Lessons From the West Africa Ebola Epidemic: A Systematic Review of Epidemiological and Social and Behavioral Science Research Priorities.* J Infect Dis. 218(**11**), 1730-1738
5. Global Preparedness Monitoring Board (2019) *A World at Risk: Annual Report on global preparedness for health emergencies.* Available at https://apps.who.int/gpmb/annual_report.html
6. Nuffield Council on Bioethics (2020). *Research in global health emergencies: ethical issues*. Available at: https://www.nuffieldbioethics.org/publications/research-in-global-health-emergencies
7. World Health Organization (2016). *Guidance for managing ethical issues in infectious disease outbreaks.* Available at: https://apps.who.int/iris/handle/10665/250580

Research between outbreaks can enable countries to prepare for and mitigate the risk of outbreaks. Even so, the early phases of an outbreak are typically characterised by a multitude of unanswered questions: what is the causative agent, how is it being spread, where did it originate, who is it affecting, how can it best be controlled and many others. Research across multiple disciplines is required to fill these gaps in knowledge as rapidly as possible. Yet coordination and integration of research activities across disciplines can be challenging. These challenges are even more acute when researchers and other stakeholders are from different countries: difference in language (both country and disciplinary), administrative processes, and accepted behaviours can also present obstacles to productive collaboration. Past controversies over sample and data sharing and ownership have also undermined trust.

Recognising the importance of integrating different disciplines to answer these critical questions, the AMS, the MRC and the IAP organised a two-day workshop to examine the key roles that interdisciplinary research could play in epidemic preparedness and response and how such research could be facilitated. Participants from 29 different countries, including public health experts, researchers from multiple disciplines, and funders, identified research priority areas tractable to multi- or interdisciplinary research approaches. They also identified potential obstacles based on lessons learned from previous outbreaks and ways they might be overcome.

The terms multi- and interdisciplinary research are defined as follows:

Multidisciplinarity draws on knowledge from different disciplines but stays within their boundaries.[8]

Interdisciplinary research is a mode of research by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or area of research practice.[9]

8. Choi BC & Pak AW (2006). *Multidisciplinarity, interdisciplinarity and transdisciplinarity in health research, services, education and policy: 1. Definitions, objectives, and evidence of effectiveness.* Clinical and Investigative Medicine 29(**6**), 351-64.

9. Committee on Facilitating Interdisciplinary Research, Committee on Science, Engineering, and Public Policy (2004). *Facilitating interdisciplinary research.* National Academy Press, 2.

Priorities for interdisciplinary research

Participants considered four key phases of epidemic preparedness and response – 'prepare', 'prevent', 'respond' and 'recover' (Figure 2) spanning public health and research disciplines.

In the domain of public health, in the inter-epidemic prepare phase, countries need to put in place the mechanisms to ensure they can rapidly and effectively prevent and respond to outbreaks. The 'prevent' phase highlights the importance of ongoing activities to protect the general public and to minimise the spread of infections; it recognises that new infections are inevitable, but timely detection and investigation can prevent them developing into epidemics and pandemics. In the 'respond' phase, mechanisms established in advance are activated to manage and control an emerging epidemic. The 'recover' phase should provide an opportunity for reflection so that lessons learned can inform future preparedness, prevention and response activities.

Running in parallel to public health measures –and often intimately connected to them – are a range of research activities. Researchers often contribute to public health responses, for example in an advisory capacity to provide evidence for decision-making.

Within each phase of preparedness and response, participants identified multiple areas of research that would benefit from a multi- or interdisciplinary approach (Figure 3).

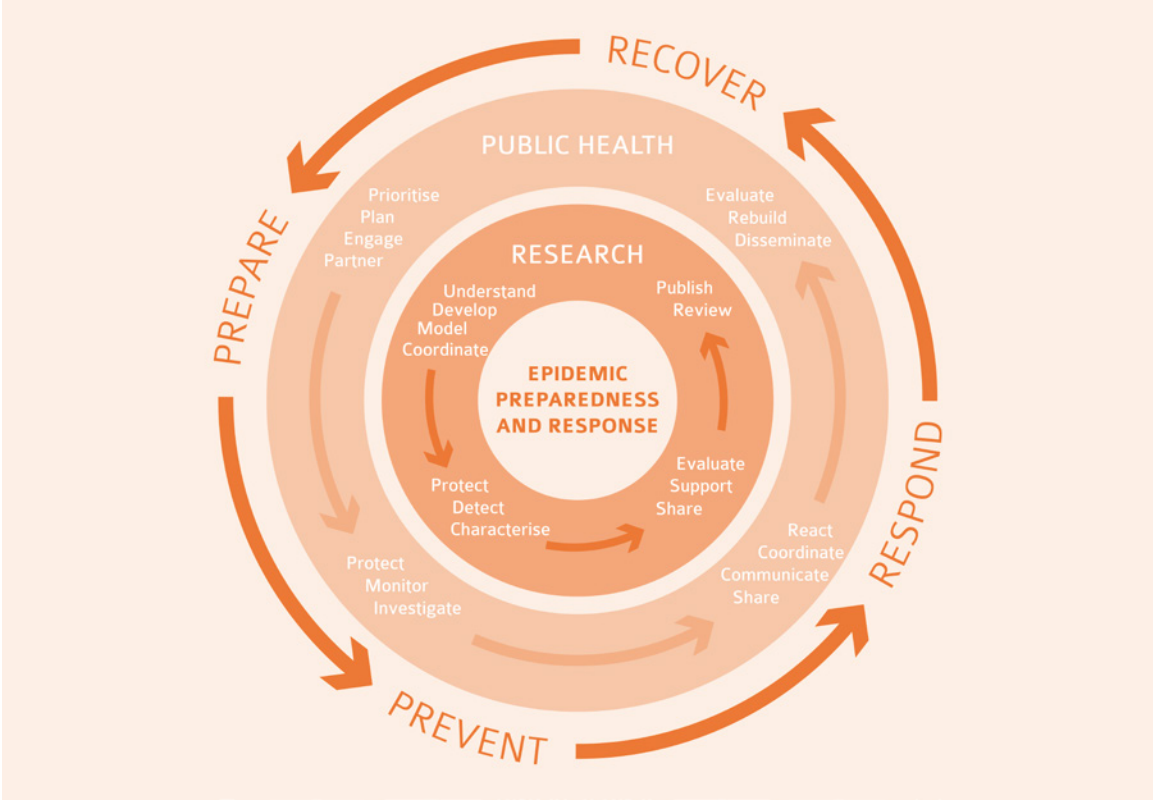

Figure 2: Four phases of epidemic preparedness and response, with associated public health and research priorities. Based on a graphic developed by Dr Gail Garson and Dr Jolyon Medlock.

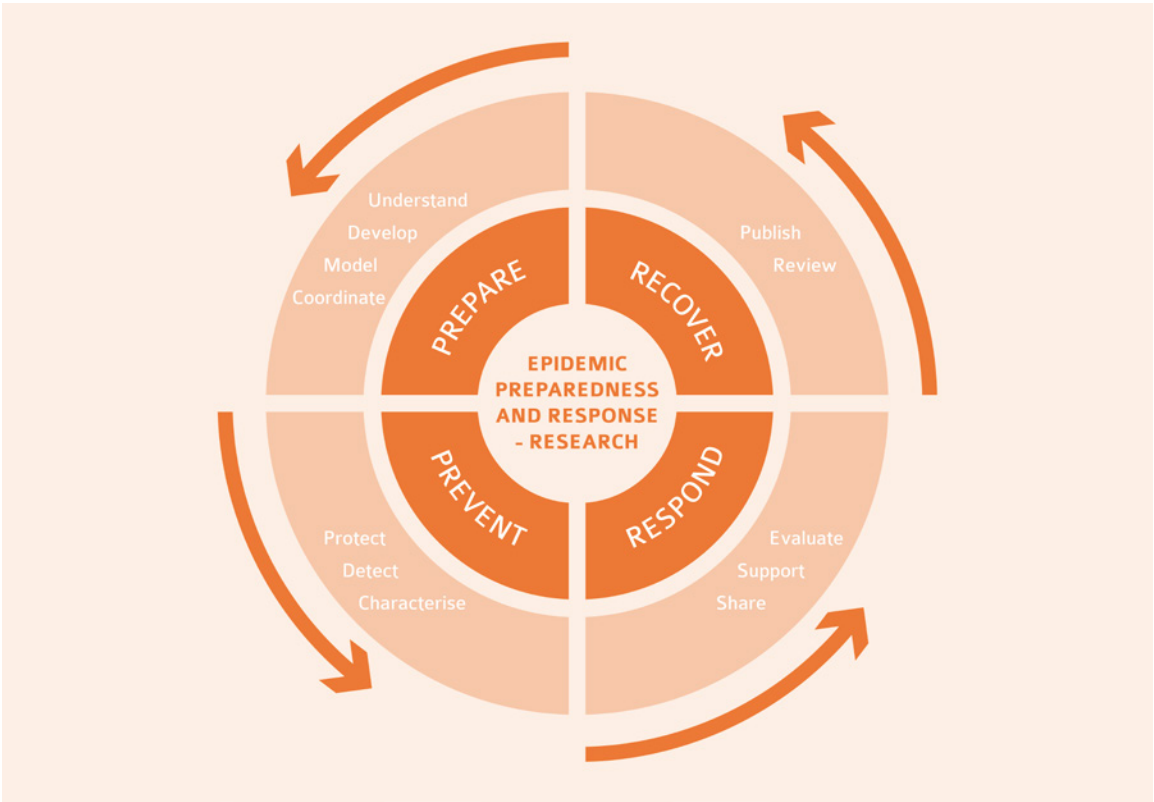

Figure 3: Interdisciplinary research priorities for epidemic preparedness and response.

PREPARE: Inter-epidemic research to improve detection, control and response capabilities

Understand: In an inter-epidemic period, a key role for research is to improve understanding of pathogens of epidemic potential and host responses, including their interactions. This is largely the domain of fundamental biomedical research, but a wide range of experimental techniques can be applied to understand pathogen biology and host protection and susceptibility. This understanding will be central to the development of new vaccines, diagnostics, and drug treatments.

A wider range of disciplines is required to generate a deeper understanding of disease transmission, for example within households, communities and in healthcare facilities, and through the environment. 'One health' approaches are likely to be required to include consideration of animal-to-human transmission, vector biology, and the role of environmental factors in facilitating the spread of disease. Such work has the potential to reveal key areas that can be targeted to interrupt transmission.

People's attitudes and behaviours have a major impact on disease transmission and the effectiveness of interventions. Social, behavioural and cultural research can provide insight into community cultural norms and individual attitudes and behaviours that influence the spread of infection, again suggesting potential points of intervention and factors to consider in the design of risk communication and behaviour-change interventions.

Integration of these different perspectives, alongside work on the wider social, environmental and political determinants of health, can provide insight into the factors underlying community susceptibility to infectious disease. This has the potential to inform longer-term structural reforms that provide greater resilience to infectious disease, alongside other social, health and developmental benefits.

The climate emergency is resulting in profound changes in weather patterns, the environment, and human behaviours that will affect the risk of infectious disease outbreaks. As illustrated by research in Malawi (Example of Interdisciplinary research 1), interdisciplinary studies can explore interactions between people, animals and the environment, and the likely implications of climate-driven changes.

A specific area to examine is the role of health systems and individual healthcare workers. Healthcare facilities can be major contributors to the spread of infections, and individual healthcare worker training and behaviour can do much to reduce the risk of transmission (or, conversely, promote the spread of disease). Multi- and interdisciplinary research into health system organisation and processes, as well as healthcare worker behaviour, can reveal key vulnerabilities and highlight opportunities to strengthen infection prevention and control. Development of the Ebola isolation cube, for example, depended on understanding of disease transmission, healthcare system practices and cultural preferences.[10]

Ultimately, preparedness depends on political commitment and stability, both nationally and globally. A political science perspective can provide valuable insight into political decision-making, potentially offering opportunities to promote greater prioritisation of preparedness and evidence-informed policymaking.

10. Alliance for International Medical Actions (ALIMA). *Cube, the Biosecure Emergency Care Unit.* Available at https://www.alima-ngo.org/en/alima-cube

Example of Interdisciplinary Research Box 1: Health, livelihoods and climate change

Dr Sosten Chiotha's work around the Lake Chilwa basin in Malawi illustrates the complex range of factors that can influence the spread of infections, and the volatility already being generated by climate change.

Lake Chilwa is the second largest lake in Malawi and at one time supplied more than a third of all fish in Malawi. The basin area is home to 1.5 million people.

Cholera is endemic and occasional outbreaks occur, as in 2011, usually during the wet season. Particularly vulnerable were fisherman living in floating huts, who dispose of waste directly into the water and also draw drinking water from the lake – practices that have remained unchanged for hundreds of years. The lake was also affected by extended algal blooms in 2012, leading to many deaths.

Dr Chiotha has studied the lake for many years. It is subject to seasonal variations in water levels, but these have become extreme in recent years, probably as a result of climate change. Indeed, a recent cholera epidemic occurred during the dry season when lake levels were unusually low due to drought conditions. Changes are also being seen in the bird life on the lake, and in the bird-catching behaviour of local inhabitants as food shortages have worsened.

The lake and basin area therefore provide opportunities to explore the complex interactions between the environment, human geography and behaviour, and animal ecology with respect to infectious disease outbreaks and human health, and in the context of profound changes driven by climate change. Such holistic or systems-based approaches are still comparatively rare. Where they have been established for other purposes, sites of environmental research may offer opportunities for socially and environmentally embedded research on infectious disease outbreaks and health.

https://www.weadapt.org/knowledge-base/ecosystem-based-adaptation/lake-chilwa-adaptation-programme

Develop: Development of intervention strategies (diagnostics, vaccines and drug or other treatments) and their uptake and deployment requires interdisciplinary research efforts and joint public and private sector collaborations.

There is also great potential to involve a wide range of disciplines, such as the physical and environmental sciences, chemistry and engineering in the development of innovative diagnostics, vaccine delivery technology, and mechanisms of drug delivery. In particular, advances in nanotechnology, often allied with mobile phone-based technologies, are creating exciting opportunities for more flexible point-of-care diagnostics. Approaches using human-centred design are important for ensuring that the development of tools is informed by the user's perspective.

Digital technologies are also opening up exciting new opportunities for data collection and surveillance. Tools have been developed for reliable digital data collection in remote settings, facilitating rapid analysis of data and more efficient data management and sharing. However, in most settings, it remains highly challenging to access high-quality routine clinical data for research purposes.

Model: Models can be used to gain a deeper understanding of factors (e.g. extreme weather events, climate change, abiotic factors, species interactions and movements) affecting disease ecology, dynamics, distributions, transmission and outbreaks and identify areas or populations at increased risk to enable public health authorities to prioritise control efforts and enhance response capabilities.

Modelling requires collaboration with mathematical and computer modellers, as well as with users and specialists in human–computer interactions to ensure that information is made available in a form that can be efficiently acted upon. Examples include the D-MOSS initiative to predict dengue outbreaks (Example of Interdisciplinary research 2) and tools to improve forecasting of malaria outbreaks, to guide prevention and preparedness activities.[11]

Modelling also provides opportunities to explore the impact of different interventions and control strategies. Pharmacokinetic and pharmacodynamic modelling can help to guide therapeutic strategies for individuals. Wider-scale modelling can be used to compare different control strategies (such as approaches for vaccinating at-risk populations) or to assess the impact of imperfect or imperfectly executed control measures. Such analyses can feed directly into public health decision-making. With a few exceptions, modelling typically does not take into account behavioural components. In part, this reflects the challenge of integrating qualitative evidence into quantitative models.

A related area is modelling of the cost-effectiveness of interventions. In resource-constrained environments, choice of intervention will inevitably depend on affordability and cost–benefit analyses. In addition, investment decisions to enhance preparedness are likely to require justification on economic grounds as well as on health benefits. One specific challenge will be to ensure that such analyses include the full social costs of epidemics: not only their direct healthcare costs, but also including their wider economic impacts – such as lost productivity due to illness and care duties, and impacts on trade and tourism, as well as direct healthcare costs.

However, economic analyses are challenging, as preparedness activities are an act of risk mitigation and it is hard to make firm and accurate assessments of the costs they have averted. Novel approaches, potentially drawing on other fields with a longer history of risk assessment, may be needed to estimate return on investment.

Coordinate: Responses to epidemics require coordinated multidisciplinary teams, in research as well as public health. These can be deployed rapidly and effectively only when national, and sometimes international collaborations have been established in advance, so that relationships can be formed, trust built, and processes developed that can be initiated when outbreaks arise. Consortia can facilitate the exchange of expertise and materials, and build capacity in affected countries.

Central to such international consortia are agreements on contentious issues such as sharing of samples and data as well as accreditation in published outputs. Bodies such as the Global Health Security Initiative and Global Research Collaboration for Infectious Disease Preparedness (GloPID-R), an international coalition of funders, are making important contributions to the development of principles to guide research in epidemic settings. The R&D Blueprint is also actively considering appropriate norms and standards in areas such as clinical trial design and data and sample sharing.

11. Abdus Salam International Centre for Theoretical Physics. *Forecasting Malaria: Climate models for public health at ICTP.* Available at: https://www.ictp.it/about-ictp/media-centre/news/2019/2/tompkins-agu.aspx

Example of Interdisciplinary Research Box 2: Dengue forecasting Model Satellite-based System (D-MOSS)

D-MOSS is a system that combines Earth observation from satellite data with weather forecasts and a hydrological model to predict dengue epidemics up to six months in advance.

A mosquito-transmitted virus, dengue is a growing public health threat in South-East Asia and elsewhere. Transmission is affected by multiple factors, including rainfall and water levels, which impact on the survival of mosquito larvae.

The multidisciplinary D-MOSS team has developed a model to predict local risks of dengue outbreaks up to six months in advance by integrating Earth observation and meteorological data with a hydrological model and a model of dengue fever. These risk predictions provide public health authorities with the tools to prioritise control efforts and to prepare for outbreaks.

Funded by the UK Space Agency's International Partnership Programme, D-MOSS was introduced in Vietnam in 2019 and is being extended to six other South-East Asian countries. The D-MOSS team is also working on tools to identify the potential long-term impacts of climate and environmental change on dengue epidemiology. Its technology is also potentially applicable to other mosquito-transmitted pathogens.

https://www.healtheuropa.eu/d-moss-an-integrated-dengue-virus-early-warning-system/89485/

PREVENT: Maintain ongoing activities to protect populations and disrupt transmission

Protect: Based on a thorough understanding of pathogens and their transmission, interventions can be developed and tested. As well as vaccines and drugs, other types of public health intervention can also reduce the risk of disease transmission, such as vector control or improved sanitation. Moreover, disease control strategies may require a combination of approaches, of which vaccines and drug treatments are just two elements. Ebola control, for example, will depend on disease identification, vaccination, treatment, isolation and safe burial practices, among other measures. When countries are affected by conflict and community mistrust, as in the ongoing Ebola outbreak in the Democratic Republic of the Congo (DRC), such control measures are extremely difficult to implement.

As vividly illustrated by Ebola, public health interventions will only be successful if they are understood and supported by communities. Hence, interventions need to be based on strong community support and a deep understanding of factors contributing to transmission. There are also opportunities to engage communities in the co-creation of locally appropriate interventions.

As well as developing and evaluating public health interventions, researchers can also offer advice to shape public health initiatives (for example on infection prevention and control in health facilities or on increasing vaccination coverage), promoting the use of evidence-based approaches. Research teams could also support public health officials in interdisciplinary evaluation of such initiatives, to encourage cycles of continuing quality improvement.

Detect: Monitoring and surveillance are critical to the detection of infectious disease threats, and are inadequate in many countries. Surveillance is a core function of public health and animal health systems, but the research community can contribute to national surveillance through its research-oriented activities, and provide public health authorities with guidance on new diagnostic tools and surveillance strategies. Researchers can work with public health authorities on integrated approaches spanning human and animal medicine, and on surveillance data management and visualisation to support rapid action.

Interdisciplinary collaborations can also generate innovative new tools for detecting incipient outbreaks, for example through automated analysis of social media posts. Trawling of online information may also highlight patterns in the dissemination of misinformation through social networks, as well as the source of misinformation, enabling public health authorities to adapt and target their community engagement activities. The US company Novetta has used this approach to provide rapid feedback to public health authorities in insecure areas of the DRC battling the Ebola outbreak (Example of Interdisciplinary research 3).[12]

Researchers can also contribute to multidisciplinary outbreak investigation and response teams. Clusters of cases may be an early warning sign of an outbreak, but uncovering the source of an outbreak and pathways of transmission may call for extensive detective work spanning discussions with individuals and communities, clinical investigation, and analysis of environmental samples.

Characterise: Effective disease control benefits from identification not just of causative pathogens but increasingly also of specific strains of a pathogen, particularly through genetic and genomic analyses. This may have immediate clinical benefit, guiding treatment, but can also provide information on the origin and spread of a pathogen and chains of transmission, informing disease control efforts. Applications in the near future could include evaluation of portable genome sequencing technology in outbreak settings.

12. Novetta. *Ebola in the Democratic Republic of Congo: Novetta Mission Analytics.* Available at https://www.novetta.com/2019/06/ebola-in-the-democratic-republic-of-congo-novetta-mission-analytics/

Genetic sequence data is also the principle tool for developing initial diagnostic tests (e.g. via PCR) with the benefit that such tests can be developed and used quickly in any suitable laboratory (the new 2019 Coronavirus, SARS-CoV-2 is a good example of this).

Example of Interdisciplinary Research Box 3: Monitoring community sentiment

US company Novetta has developed an innovative approach for rapidly detecting community perceptions and behaviour patterns, illustrating the potential power of new informatics tools in outbreak contexts.

It has created tools that mine a wide range of openly available data sources, such as social media (WhatsApp, Facebook, Twitter), print and broadcast media (radio and television) and inputs from local teams. Its innovative technology is able to integrate and cross-reference these data, providing near real-time insights into the transmission of messages on emerging threats through social networks.

By providing information to public health authorities within 24–48 hours, Novetta's tools can generate insights about knowledge and attitudes in hard-to-reach areas, to inform the implementation of community engagement activities, without exposing researchers to the dangers of working in insecure areas. Remote collection of information also removes a potential source of bias associated with face-to-face contact.

One application has been in the DRC, where the technology has been used around sites involved in clinical trials of Ebola interventions. The rich data collected have provided valuable information to clinical trial teams on the origins and spread of misinformation, and also early warning signs of threats to facilities or operations. The tool has also provided a mechanism to assess the impact of community engagement exercises.

https://opendocs.ids.ac.uk/opendocs/bitstream/handle/20.500.12413/14558/SSHAP_data_compilation_brief_No3_February_May_2019.pdf

RESPOND: Activate epidemic response plans to extinguish emergent epidemics

Evaluate: Epidemics provide unique opportunities to gather information on the efficacy and effectiveness of new vaccines and drugs. In the past five years, extensive efforts have been undertaken to ensure that clinical trials of experimental interventions can be rapidly launched in emergency settings, as achieved with studies of both vaccines and treatments in the current DRC Ebola epidemic in the DRC, based largely on lessons learned from the earlier West Africa Ebola outbreak.

Researchers also have a key role to play in advising on appropriate public health responses in emergency settings. The 2014–16 West Africa Ebola outbreak highlighted the key role of effective community engagement, lessons that have been applied in the DRC. Similarly, interdisciplinary approaches have been used to understand community perceptions of Nipah virus in Bangladesh and inform public health behaviour change interventions to prevent infection.[13]

As well as formal clinical trials, more opportunistic analysis of clinical or public health data may be able to inform treatment or public health responses. Although such data may be of lower quality, difficult to access and subject to more biases, careful analyses can still provide useful insights.

A further potential role for research is in evaluation of the efficiency and effectiveness of emergency responses. Embedding interdisciplinary operational research could provide insights to guide future responses and inform the strategies developed in other locations.

Support: Researchers hold specialist knowledge and skills that could be required during emergency situations. Ad hoc opportunities may arise to apply this knowledge and skills to improve epidemic responses. For example, the attitudes and behaviour of communities and healthcare workers will have a significant impact on control activities. Insights from all disciplines need to be made rapidly available and presented in a format that is usable by decision-makers.

Share: Past epidemics have been marked by a reluctance to share samples and data, to the detriment of public health responses. With effective preparedness, principles and processes should be in place to ensure rapid and equitable sharing of both data and samples. Development of biobanks will enable samples to be maintained for future analyses, subject to agreed procedures.

13. Parveen S, et al. (2016) . *It's not only what you say, it's also how you say it: communicating nipah virus prevention messages during an outbreak in Bangladesh.* BMC Public Health 16, 726.

RECOVER: Reinstate structures and learn lessons to inform future activities

Publish: An important contribution of researchers is to publish their research and make data available as rapidly as possible, ideally in open access repositories. This will facilitate pooling of data and additional analyses, and help to ensure that all future decision-making is based on full data.

Review: To complete the cycle, lessons learned from responses to epidemics should inform future national, regional and global preparedness activities. One role for researchers is to contribute to post-action multidisciplinary evaluations, not to apportion credit or blame, but to ensure future responses are more effective.

There are also opportunities to carry out impact assessment research, to add to the evidence on the impact of particular pathogen outbreaks. Ideally, these assessments should cover the full range of health, social and economic impacts, and feed into future cost-effectiveness analyses and decision-making.

Facilitators of interdisciplinary research

As well as the above priorities for interdisciplinary research, participants also identified a range of obstacles to research involving different disciplines as well as the following ways they might be overcome.

Establish multidisciplinary consortia: Relationships and working processes take time to establish, so ideally consortia need to be developed well in advance of emergency situations. Differing vocabularies, research traditions and practical ways of working can present significant barriers. By addressing such issues in a frank and transparent way during inter-epidemic periods, trust can be built and strong working relationships established. The ZIKAlliance consortium (Example of Interdisciplinary research 4) is seen as one highly successful example.

Break disciplinary barriers: Institutional divisions can be a further barrier to interdisciplinary working. Within discipline-specific departments, researchers may have little exposure to fields outside their own. Even if they are interested in establishing interdisciplinary collaborations, they may not know suitable collaborators. Institutions could do more to facilitate cross-departmental working, while online 'matchmaking' platforms could help researchers identify potential collaborators. Engaging early-career researchers in interdisciplinary collaborations may help to promote bonding between groups. In addition, it is important to establish a culture of openness by sharing research and practices routinely.

Strengthen community engagement: Epidemic responses will fail if they are not accepted and supported by communities. Effective community engagement, particularly through community leaders, is therefore as important as development of disease control tools. Building trust with communities also takes time and effort, and benefits from the expertise and insights of social scientists and other community contacts. Communities need to be seen not simply as the objects of study but as partners in the development of solutions to the challenges they face, and given a voice in the planning and organisation of research.

Encourage funder buy-in: Interdisciplinary research is typically more difficult to plan and carry out, and harder to secure funding for. It is important that funders recognise the challenges of interdisciplinary research – as well as the benefits it provides. This may mean greater collaboration across funding agencies in the medical, veterinary, physical, environmental, social sciences and humanities, as well as use of funding mechanisms that acknowledge the difficulties that interdisciplinary research proposals often face in conventional peer review process. This could, for example, mean establishing interdisciplinary research-specific funding schemes or other initiatives to promote interdisciplinary working.

Example of Interdisciplinary Research Box 4: ZIKAlliance

ZIKAlliance is a multinational and multidisciplinary research consortium comprising 54 global partners. It is coordinated by Inserm, the French National Institute of Health and Medical Research, and funded by the European Union's Horizon 2020 Programme.

The programme is investigating clinical, fundamental, environmental and social aspects of Zika virus infection. In particular, ZIKAlliance is focusing on the impact of Zika virus infection during pregnancy and the natural history of Zika virus in humans and the environment.

In collaboration with two other EU-funded consortia (ZikaPLAN and ZIKAction), ZIKAlliance is also working on the development of a preparedness platform in Latin America and the Caribbean.

ZIKAlliance is based on a global One Health approach, and draws on a network of existing clinical cohorts across South America. It has provided a global framework that facilitates the sharing of techniques, materials and data, and the standardisation of experimental approaches. It has a strong emphasis on building a sustainable research network in Latin America and the Caribbean to enhance preparedness for future epidemics.

It also emphasises early and deep engagement with communities, maintaining the flexibility to respond to the changing epidemiology of disease, and harmonising processes to facilitate joint working. It has also established a robust ethical framework, including international good practice in areas such as sample and data ownership and benefit sharing.

https://zikalliance.tghn.org

Promote national ownership: Strong political commitment to preparedness and to research is essential. Governments need to commit to developing the infrastructure and systems for effective surveillance and emergency responses, promoting integrated cross-departmental strategies (e.g. a One Health approach). Researchers may need to increase their political engagement and advocacy to encourage greater commitment to preparedness. However, health systems may be limited in many countries at risk of outbreaks, and partner support will be necessary to build preparedness and response capacity.

Recognising the importance of national ownership, externally funded research activities need to include a focus on building local research capacity, engaging with local policymakers, and ensuring that projects align with national research priorities. Ideally, national preparedness research strategies need to be developed collaboratively, with the involvement of key national stakeholders such as national public and animal health institutes.

Build research capacity: There is a need to develop research capacity across multiple areas in countries and regions at risk of epidemics. As well as specialist expertise in priority areas, the capacity to take part in interdisciplinary research projects also needs to be developed. Institutions as well as individuals should look to enhance opportunities for interdisciplinary collaboration. International collaborations – North–South and South–South – could play a crucial role in research capacity building, as illustrated by the PANDORA-ID-NET consortium (Example of Interdisciplinary research 5).

Build regulatory capacity and develop harmonisation: In emergencies, research activities should still conform to internationally recognised quality and ethical standards.[14] [15] However, research needs to begin

14. Nuffield Council on Bioethics (2020). *Research in global health emergencies: ethical issues.* Available at: https://www.nuffieldbioethics.org/publications/research-in-global-health-emergencies

15. World Health Organisation (2016). *Guidance for managing ethical issues in infectious disease outbreaks.* Available at: https://apps.who.int/iris/handle/10665/250580

Example of Interdisciplinary Research Box 5: PANDORA-ID-NET

The Pan-African Network For Rapid Research, Response, Relief and Preparedness for Infectious Disease Epidemics (PANDORA-ID-NET) is funded through a 10m grant from the European and Developing Countries Clinical Trials Partnership (EDCTP).

PANDORA-ID-NET is a multidisciplinary One Health initiative that supports broad themes addressing responses to emerging infections in Africa, underpinned by capacity development and training. The programme includes partners from 13 African and nine European institutions.

The PANDORA consortium aims to develop and strengthen effective outbreak response capacities across the whole of sub-Saharan Africa, in partnership with national governments and other international stakeholders. It aims to establish rapid response teams able to undertake public health research immediately outbreaks are identified; develop local capacity to undertake multidisciplinary research during both preparedness and response phases; train researchers, healthcare workers and others to undertake and lead public health research; and engage with politicians and policymakers to advocate for greater preparedness.

https://www.pandora-id.net/aims

as rapidly as possible, and potentially across more than one country. Building the capacity of national and regional regulatory authorities, and coordination and harmonisation of regulatory approaches, would help to ensure rapid initiation of studies.

Looking forward

Epidemic preparedness, and research associated with it, is a highly active area. An increased focus on global health security has catalysed a wide range of initiatives to ensure that countries – and the world more generally – are better prepared to detect, prevent and respond to infectious disease outbreaks and epidemics.

New product development is a high priority, and will generate the diagnostics, vaccines and treatments essential for outbreak detection, prevention and control. However, it is important not to neglect the wider research that contributes to preparedness and can help ensure new developments are used in the most effective ways. In particular, research activities need to focus on the realities of healthcare delivery, use of interventions in real-world situations, implementation of innovations within health systems, public health and animal health, and individual and community attitudes and behaviour.

New outbreaks are generally associated with uncertainty. Rapid action is required, but it needs to be coordinated and targeted where it can have most impact. While multiple domains of research can fill important gaps in knowledge, integrating insights from different types of research is rarely straightforward – particularly in the complex geopolitical contexts in which new epidemics are likely to arise. With this is mind, several areas could potentially be prioritised to nurture interdisciplinary research for epidemic preparedness and response:

- **Focusing on a holistic understanding of infectious disease transmission:** The spread of infections is influenced by a wide range of biological, social, cultural and environmental influences. A full understanding of infectious disease transmission and epidemiology will require interdisciplinary research spanning all these areas. The involvement of public health and animal health officials and policymakers can help to ensure that research is rooted in public health priorities and has more chance of influencing policy.

- **Development and evaluation of evidence-based disease control interventions:** A deeper understanding of the full range of factors influencing disease emergence, re-emergence and transmission can underpin the development of targeted interventions. Again, these interventions need to be developed and evaluated by interdisciplinary teams. Due in part to the challenges associated with interdisciplinary collaborative work, complex public health interventions have not yet received the attention given to new product development.
- **Modelling for risk assessment and response planning:** Multiparameter models have the potential to identify times and places where outbreaks are most likely to occur, and to guide the use of limited resources for prevention. They can also be used to compare different prevention strategies to inform decision-making. Over longer time frames, such models can provide insights into the potential impact of climate change, other environmental disturbances and socio-demographic shifts.
- **Learning lessons:** Opportunities exist to integrate interdisciplinary research into prevention and responses, to promote uptake of innovations and to evaluate activities. Operations and implementation research can play a key role in optimising processes and the performance of those involved in prevention and outbreak control. Although such research is challenging in emergency situations, it may generate insights that enhance responses during an ongoing epidemic or those organised in subsequent outbreaks. It is essential that lessons are learned so that national, regional and international responses to outbreaks are constantly improving

To establish a firm foundation for multi- and interdisciplinary research, the following facilitators could be prioritised:

- **Development of international partnerships:** To function effectively, multidisciplinary consortia need to be developed in advance of outbreaks, so relationships and harmonised working practices can be established. As well as improving understanding of infectious disease transmission in inter-epidemic periods, such consortia could be rapidly mobilised to provide answers to key questions during outbreaks.
- **Community engagement:** Effective community engagement, including co-designing and co-producing research with communities and other non-academic organisations, will ensure research priorities are identified from the needs of the community and will build trust and support for public health interventions.
- **Training, researcher and institutional support:** Research capacity in LMICs is generally low in many of the disciplines required for effective preparedness and response. Capacity building needs to focus not just on these individual disciplines but also on ensuring that researchers can work effectively together in interdisciplinary teams.
- **Funder engagement:** Following the 2014–16 Ebola outbreak, new product development for epidemic-prone infections has been prioritised globally, and multiple new products are in the pipeline. However, the Ebola outbreak also illustrates how new interventions are necessary but not sufficient for effective disease control. Funders therefore also need to prioritise the multi- and interdisciplinary research required to ensure best use of these interventions and the acceptability of control strategies in affected communities.

Conclusions

Throughout history, infectious disease epidemics have decimated human populations. Recent decades have seen many successes in epidemic control, preventing new infections from taking root. The example of HIV, which kills around a million people a year, illustrates the potentially devastating impact that emerging infections can have when not identified early and rapidly brought under control. For Ebola, an effective vaccine is now available, but will not by itself prevent outbreaks in the absence of community support for wider disease control activities.[16]

Transmission of infections is influenced by multiple factors – biological, environmental, behavioural, social, cultural, health system-related and political. Integrating the expertise and insights from multiple domains of research, as well as other stakeholders such as policymakers and civil society organisations, is therefore essential to ensure that countries, and the world as a whole, are better prepared for and more able to respond to outbreaks of emerging and re-emerging diseases. As well as supporting their individual efforts, governments, funders and institutions must also ensure that structures and opportunities are in place for researchers from these different domains to work together fruitfully and productively.

16. Callaway E (2019). *Make Ebola a thing of the past': first vaccine against deadly virus approved.* Nature 575(**7783**), 425-426.

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