

Framing conditions, convergence and divergence in developing interdisciplinary research capacity and collaboration: the Community Network for African Vector-Borne Plant Viruses

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ABSTRACT

Collaboration is necessary for scientific and innovative productivity leading to societal impact. It enables scientific communities to accumulate research capacity and can promote interdisciplinarity. However, there are knowledge gaps regarding the processes by which collaboration develops. Using the case study of an international community network, we explore the effects of convergence and divergence activities and individualized interactions on the emergence of scientific collaboration, leading to research capacity and interdisciplinarity.

Using qualitative research methods combined with network analytical techniques, we show that the provision of a sequenced programme of in-person and online events, involving purposeful networking, training and collaborative projects leads to the development of collaborative connections. Additionally, our study demonstrates that the coevolution of suitable framing conditions and distinct convergence and divergence practices contribute to the effective development of collaboration, capacity, and interdisciplinarity.

This study is relevant to organizations seeking to enhance scientific collaboration, research capacity and interdisciplinarity within target research communities as it provides clear, actionable approaches for implementation alongside a series of practical suggestions which can be expanded and replicated in different contexts for further benefits realisation.

Keywords: Collaboration; research capacity; interdisciplinarity; framing conditions; network convergence; network divergence.

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INTRODUCTION

Collaboration is an important mechanism for scientific and innovative productivity, enabling diverse global perspectives to shape knowledge production, and is of increasing focus of research funders. Research funders have recently invested in various collaborative networks with the aim of increasing scientific collaboration and the research capacity of academic communities in particular disciplinary and cross-disciplinary domains. In the UK, the cross-disciplinarity of funded research projects increased between 2008 and 2016 (Sun et al., 2021), highlighting increasing interests and experience in this approach.

Collaboration has become increasingly important in scientific research, co-authored JSTOR-indexed papers increasing from 20 percent to 60 percent 1950-2010 (West et al., 2013). Collaboration provides two broad categories of benefit: capacity and diversity. Accumulating capacity in technical expertise and know-how enables deployment at scale. Diversity of experience, disciplinary approaches, theory, and methods can be combined in novel, creative and innovative ways (Schumpeter 1934).

Collaboration helps to build capacity by accumulating related resources more quickly than by individual effort, increasing economies of scale by spreading fixed costs, increasing flexibility in resource deployment, learning from pooled know-how and experience (Hamel et al., 1989). Additionally, collaboration can tap complementary resources, important in the face of increased specialisation (Cole and Zuckerman, 1975), or simply different information, experiences, theory and methods, important to creativity and innovation (March, 1991).

While much is known about the outcomes, precursors and structure of scientific collaboration, there has been little study of the processes by which scientific collaboration emerges, with particular gaps existing around knowledge of the micro-level processes operating to build productive/effective, long-term research collaborations (Melin, 2000; Ruddy et al., 2005; Wöhlert, 2020). This paper addresses this gap by investigating processes by which scientific collaboration emerges.

Specifically, we investigate the following: the effect of framing conditions within which collaboration can develop on the practices by which collaboration emerges; how different activities interact to promote convergent and divergent behaviours during the emergence of collaboration in networks.

We investigate the process of collaboration by analysing a research-focused international community network initiative: the Community Network for African Vector-Borne Plant Viruses (CONNECTED). This case provides a long-lived example of funder-supported initiatives to increase collaboration and research capacity via network-based approaches, the effectiveness of which typically lacks underpinning evidence. CONNECTED provides an exemplar collaboration network which facilitated international and interdisciplinary connection, interaction, and collaboration with researchers at all career levels through in-person and online events, training and networking, and funding of new research projects.

The examination of this case enables us to go beyond existing understandings of sequential descriptions of collaboration, contributing new understanding to describe the subtle interplay of convergent and divergent activities in driving collaborative behaviours, processes and outcomes.

Our study provides evidence of the effectiveness of the community network approach for enhancing scientific collaboration, interdisciplinarity and research capacity. This approach is effective when

intentionally implemented as a phased dynamic programme of in-person and online convergence and divergence activities, including events and collaborative projects, for different disciplinary research communities, and operating within framing conditions appropriate to strategic goals and cultural contexts. This is valuable to research funders for underpinning investment of targeted support into research communities where there is strategic need.

LITERATURE

While much is known about the outcomes, precursors and structure of scientific collaboration, there has been only limited study of the processes by which scientific collaboration emerges. With regard to outcomes, collaboration enhances the quantity and quality of scientific research, as measured by citations of co-authored publications (He et al., 2009; Eaton et al., 1999; Shen et al., 2021). This is especially so where collaborators are heterogeneous by institution, gender, status, country of residence, or discipline and complementary partners are selected, albeit within small groups (Porac et al., 2004; Bercovitz and Feldman, 2011; Choi et al., 2022; He et al., 2009; van Leeuwen and Tijssen, 2000; Callaert et al., 2015; Newell and Swan, 2000; Cummings et al., 2013). There are benefits, however, from homogenous collaboration in general and within institutions, especially when collaboration builds on prior social ties and friendships (Landry and Amara, 1998; He et al., 2009; Bercovitz and Feldman, 2011; Choi et al., 2022; Zajdela et al., 2022). Collaboration builds institutional research capacity and productivity and is particularly beneficial to early career researchers (ECRs), those in STEM fields, low-ranked institutions and institutions who are geographically or organisationally close (Aldieri et al., 2018; Kodama et al., 2013; Gardner et al., 2002; Lissoni et al., 2011; van der Wouden and Youn, 2023).

In terms of precursors, scientific collaboration is pursued more by high status individuals and institutions with greater grant income, in STEM subjects, and who are geographically or organisationally close (Choi et al., 2022; Smith et al., 2023; Bozeman and Corley, 2004). High-status collaborators tend to have greater self-efficacy, optimism, resilience, hope, pragmatism, self-organisation, a 'global innovativeness' outlook and feel less time-constrained (Mocheshi et al., 2022; Melin, 2000; van Rijnsoever et al., 2008; Gray et al., 2001; Green et al., 1991). The duration of prior social ties, reciprocation, transitivity and the partner choices of others influence partner selection (Bilal et al., 2021; Powell et al., 2005; Maghssudipour et al., 2021). Women tend to collaborate more with women, seek mentors and seek interdisciplinary collaboration, whereas men tend to pursue instrumental goals and experience when selecting collaborators (Bozeman and Corley, 2004; Bozeman and Gaughan, 2011).

Scientific collaboration is structured variously, with a range of collaboration strategies pursued within the same discipline. Carayol (2003) distinguishes five major types of science-industry collaboration: medium duration; bilateral; basic research; contract research; consortium. Examining collaboration in physics, Chompalov et al. (2002) identify three additional major forms beyond the participatory single disciplinary approach assumed to characterise the field: bureaucratic, leaderless and non-specialist cross-disciplinary. D'Ippolito and Ruling (2019) find that long-term collaboration is sustained by multiple collaboration forms. Funded research collaborations are concentrated among high status universities (Powell et al., 2005; Maghssudipour et al., 2021). These tend to have more collaborative partners and collaborate more with large industry partners (Sánchez-Barrioluengo et al., 2019).

Collaboration is structured by power, particularly challenging for junior academics and academics from the Global South (Tsai et al., 2016; Bilal et al., 2021). Resource issues such as policies, bureaucracy, institutional competition, weak industry links, access to funding, and teaching load limit capacity for collaboration (Muriithi et al., 2018). Engagement with geographically distant partners, especially those in high-cost centres in the Global North, typically involves high transaction costs and communication barriers (Wagner et al., 2019). Engagement with high status and Global North partners are characterised by power imbalances and rigidities in research agendas (Shrestha et al., 2022).

While cognisant of many of the challenges involved, collaboration is thus widely pursued as an important mechanism for scientific productivity. Institutional funders such as the European Union and some UKRI funds prescribe collaboration as a condition for research funding. Researchers assemble wide consortia of specialised researchers to tackle complex research problems. But a tension exists in the forms of collaboration sought, accumulation of related resources and expertise to build capacity or the search for complementary, diverse resources and novel combinations (March, 1991).

Interdisciplinary research has become a prominent facet of research funding schemes as a means to advance knowledge and generate societal-scale solutions to grand challenges that cannot be achieved by a single discipline. Beneficial outcomes of multi- and interdisciplinary research include increases in academic productivity and short- and long-term funding, despite short-term reductions in output impact (Leahey and Barringer, 2020; Sun et al., 2021). However, as with scientific collaboration, the processes by which interdisciplinarity emerges are poorly understood. Broad-level factors play a part in the early stages, such as institutional structuring of researchers into interdisciplinary units (Leahey and Barringer, 2020), enabling researchers who bridge disciplines to act as knowledge brokers between disciplines, enhancing long-term funding (Sun et al., 2021). Dalton et al. (2022) suggest that achieving interdisciplinary research goals requires establishment of a central organizing principle, “a catalytic mechanism that coalesces the intentionality of system agents through a unification of their disparate aims and methodologies, thereby directing multiple monodisciplinary agents towards a point of convergence” (Dalton et al., 2022). This central organizing principle enables collaborations to become mechanistic, providing better directionality towards task completion, converting new interdisciplinary knowledge into action. It can be imposed by research funders top-down or develop in an experience-driven way by individuals recognizing the need for formalized collaborations to reach goals, and be facilitated or inhibited by institutional barriers. Movement from knowledge heterogeneity towards knowledge integration across disciplines, underpinning interdisciplinary research and leading to disciplinary reciprocity and new communities of expertise and practice, is affected by social network structure (Zhang, 2023). It is therefore important to consider the type of social interactions that develop in the formation of epistemic communities where knowledge integration can occur.

Collaboration as process

Good governance in partner selection and management of collaborations is widely advocated but what makes ‘good’, particularly at the micro-level? Some stylised sequential descriptions of the collaboration process have been offered, echoing similar organisational behaviour models of group formation, such as Tuckman's (1965) ‘forming, storming, norming, performing’ heuristic (see Table 1).

Table 1. Stylised sequential descriptions of collaboration

Reference	Stages				
Kraut et al. (1987)	Initiation			Execution	Public Presentation
Gitlin et al. (1994)	Assessment and goal setting	Determining collaborative fit	Resource identification and reflection	Project refinement and implementation	Evaluation and feedback
Sonnenwald (2007)	Foundation		Formulation	Sustainment	Conclusion
Perry-Smith & Mannucci (2017)	Generation		Elaboration; Championing	Implementation	

Source: Adapted from (Ju et al., 2022)

Each stage of these sequences involves different relational needs. Initial stages involve potential partner assessment, sharing assumptions, trust building, idea generation (Kraut et al., 1987; Gitlin et al., 1994; Sonnenwald, 2007), reciprocation, negotiation and renegotiation (Gitlin et al., 1994) and cognitive flexibility and non-hierarchical association (Perry-Smith and Mannucci, 2017). Physical proximity and frequent interaction aids assessment of potential collaborators, at low cost in workplaces but also in informal meetings and academic conferences (Kraut et al., 1987; Lambert, 2003). Foundation is aided by clarity of scientific, political and socioeconomic goals, resource accessibility (Sonnenwald, 2007) and social identity via social networks and personal compatibility (Sonnenwald, 2007; Gitlin et al., 1994; Melin, 2000). Trust at the formation stage has low resilience, based on judgements of commitment and competence (Newell and Swan, 2000).

Contact evolves into collaboration through two main paths: via frequent informal interaction or via formal proposal, sometimes brokered by a high-status intermediary. Following a decision to collaborate, supportive interactions such as constructive criticism to reduce uncertainties becomes central (Perry-Smith and Mannucci, 2017); a task-oriented ‘second meeting’ is a critical consolidation step. This involves multiple face-to-face interactions over an extended period, to develop a project plan, centred on “spontaneous, informal and unstructured exchange of ideas ... [typically involving] ... high energy levels and a high level of concentration ... a primary benefit of collaboration” (Kraut et al., 1987, p. 40). The formalisation of collaboration involves documentation, project management, leadership and organizational structure; and greater use of information and communication technology (ICT) over in-person meetings (Sonnenwald, 2007); (Freeman et al., 2014). Equitable participation, diverse resources, trust, learning, sufficient communication, realism and flexibility are important to sustained collaboration (Sonnenwald, 2007; Hackman, 1987; Lohfeld and Brazil, 2000). Throughout the execution stage, trust developed as people get to know each other through ongoing reciprocal exchange is more resilient than the initial forms of trust (Newell and Swan, 2000; Bozeman et al., 1999).

Despite these various observations, the process of building effective and sustained research collaborations remains not well-understood, especially the micro-level processes at play (Melin, 2000, Ruddy et al., 2005) lamenting the absence of ‘high quality studies’ in the area and (Wöhlert, 2020, p153) finding that in international research collaborations, ‘empirical analyses on the actual communication processes among scientists are still rare’.

Research Questions

We respond to the challenge of greater understanding the process of developing academic collaboration leading us to ask whether there are general principles of and practices for effective collaboration, particularly in interdisciplinary settings. From the literature we find it useful to distinguish framing conditions and practices.

Framing conditions or parameters place limits on the scale and scope of collaboration. This is particularly so for institutionally-driven collaborations where there are greater demands of accountability for outcomes. Prominent parameters include the vision or strategic goals of the collaboration (Sonnenwald, 2007), its geographic reach (Smith et al., 2023) and available financial and technological resources (Sonnenwald, 2007). These influence the priorities set for the collaboration and the types of practices adopted. Goals supported by limited resources will be best met by rapid convergence on solutions. More extensive goals and resources can favour greater exploration before convergence.

While the framing conditions provide an initial set of parameters that structure the opportunities for social interaction, the actions of participants also impact on the framing conditions (Archer, 1995). The experiences of collaborative practices, manifested primarily in collective events, feedback to adjust the framing conditions for further/onward collaboration; resources are shifted from less to more fruitful practices, and strategies are reviewed. This leads us to ask *how do framing conditions determine practices and how do practice outcomes reshape framing conditions?*

We argue that the practices of participants in the collaborative network, particularly the practices of organisers, determine the prevalence of convergent or divergent behaviours in events. A tightly scheduled conference structured around workgroups tasked with many specific outcomes and few social activities will have fewer opportunities for the emergence of authentic meaningful relationships than one that allows participants to pick and mix among presentations alongside a rich social programme. On the other hand, an insufficiently structured event may prompt participant disengagement, limiting opportunities for interaction or collaboration. This leads us to ask *what practices give rise to convergent behaviours and which give rise to divergent behaviours in events organized to develop collaboration?*

EMPIRICAL CONTEXT

The empirical context of this study is provided by the Community Network for African Vector-Borne Plant Viruses (CONNECTED), a research project co-led by the University of Bristol and Newcastle University, funded by a £2M UK government Global Challenges Research Fund (GCRF) grant. CONNECTED operated from 2017 until late 2023 as one of four other vector-borne disease (VBD) community networks funded through the same scheme. CONNECTED had the following specific objectives:

1. To build a sustainable and long-lasting network of multi-disciplinary international scientists, to address the problems created by plant viral VBD.

2. To run a series of activities to promote and embed interdisciplinary working and to strengthen research capacity, capabilities and methodologies particularly focused on the vectors of plant disease.
3. To use pump prime funding for a range of innovative projects identified by the Management Board of CONNECTED ultimately leading to more competitive, collaborative, cross-disciplinary and integrative research proposals, as well as real impact.
4. To capacity build, via improved communication and collaboration networks, seminars and workshops, and training courses both in the UK and Sub-Saharan Africa (SSA).
5. To develop early career researchers (ECRs), by focusing part of the pump-primed funding on proposals submitted by them, providing support to enable proposal development and delivery of projects.
6. To support collaboration between researchers in the UK and low- and middle-income countries (LMICs) and engagement with end-users, stakeholders and policy makers.
7. To provide legacy benefits from the network by facilitating the opportunity for further funding for the projects bringing the greatest impact to the region.

As such, the primary goals of the CONNECTED Network were to stimulate interdisciplinary and international collaborations, and increase research capacity, in vector-borne plant virus research, specifically between the UK and SSA countries on the OECD DAC list. Being funded through the GCRF set particular terms and conditions for how funds could be spent, shaping the network activities programme. The project included a ringfenced budget for pump priming new international plant viral VBD research projects.

The network was coordinated by a Network Team made up of an Executive group (lead academics and Network Managers: 1 FTE, job-share), supported by a Communications Officer and Executive Assistant (both 0.4 FTE). The Network Team designed, implemented and evaluated the programme of activities. From the outset, network governance was overseen by a group of approximately 20 experts in plant virology, entomology, plant health and agricultural impact from across the UK and SSA. Early in the project, the Network established an actor-centred linear Theory of Change approach to guide the programme of activities towards long-term influence and impact on smallholder farming contexts in SSA (Figure 1). This focused the activities of the network into three overarching themes: pump-priming new collaborative research projects, training and capacity building, and networking opportunities (mostly in-person/online events and small travel grants).

The Theory of Change was underpinned by a monitoring, learning and evaluation (MLE) system to track progress: this used surveys, case studies, and web-based analytics to monitor event participation, learning and development outcomes, digital resource utilisation and reach. Outreach, engagement and publicity to researcher and stakeholder audiences were managed via a communications strategy: project website including news blog, social media channels, monthly e-newsletters, and bespoke internal/external relations.

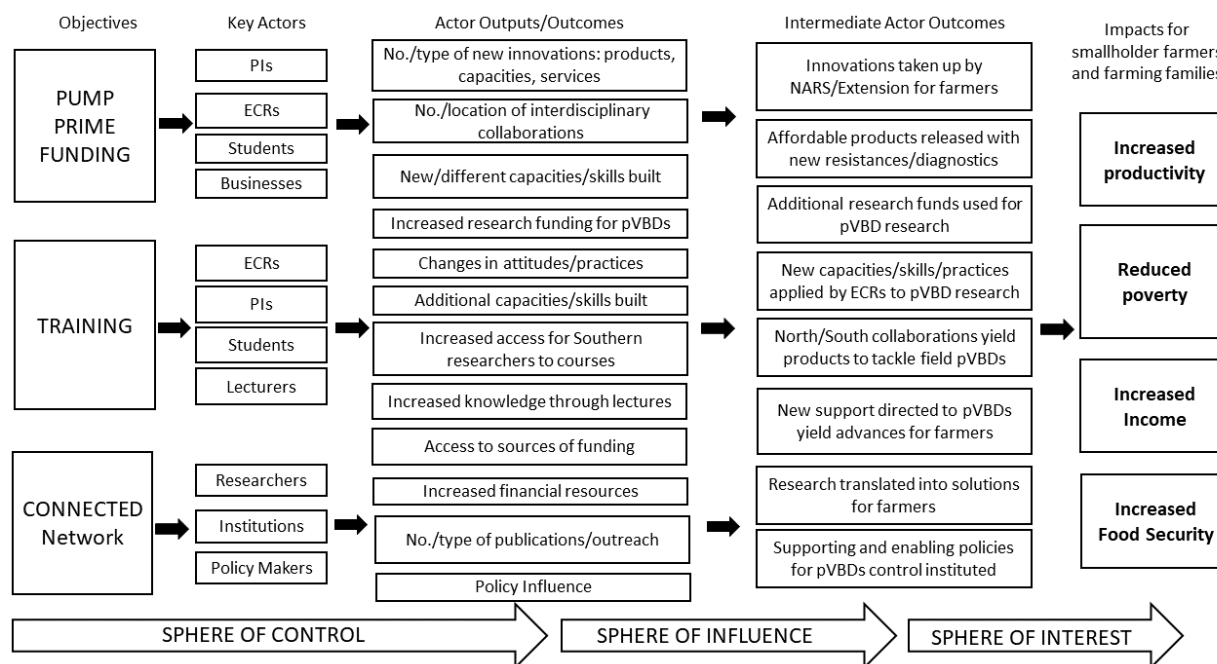


Figure 1: Actor-centred linear Theory of Change developed for the CONNECTED Network. From left to right this shows the three themes of activities designed to achieve network objectives and the key actors to whom these activities are relevant. It then identifies the outputs and outcomes for those actors resulting from engagement with the activities, outcomes for intermediate actors (who are not shown), and the impact ultimately desired. Along the bottom, arrows highlight the spheres of control, influence and interest for implementors of the Theory of Change.

Network activities programme

The three activity themes, pump priming new research projects, training and capacity building, and networking, were organised into an interlinked programme. The initial timeline of the grant set the sequence of this: networking opportunities had to precede pump prime funding (PPF) opportunities to enable collaborative connections to form, and to identify research community needs for targeted capacity building. Initial outreach and engagement activities focused on accruing new membership in target sectors, bringing the early membership together for two in-person launch conferences, the first in the UK, the second in Uganda. These first in-person meetings identified community needs and co-produced research priorities which were communicated to the entire network membership and around which the ensuing programme of activities was designed.

The pump prime funding (PPF) calls opened immediately following the conferences, enabling international teams to bid for small awards (£30,000-£90,000). Previous Management Board experience indicated that sums of approximately £30,000 and of 1-2 years duration are effective at generating momentum, impact and follow on funds. These two, two-stage calls (expression of interest followed by invited full submission) led to a funded portfolio of 20 research projects involving 55

researchers from 33 institutions across 14 countries, working on 11 different crops. While the funded projects represent operational international collaborative projects, the expression of interest stage was an important precursor stage to full scientific collaboration: 56 teams coalesced around priority research questions to submit project outlines as expressions of interest, the drafting of which necessitated online interactions following the in-person conferences. PPF projects had to have clear end points to enable completion within the original end dates of the CONNECTED grant and impact harvesting; additional value-adding activities (communications, resource provision) could run in parallel.

The ensuing programme of network activities is outlined in Table 2. These include: PPF research project operation; in-person and online conferences, workshops, research/special interest seminars, training courses; training grant schemes (for attending third-party training courses or conducting educational visits to other research groups), a hybrid training offering co-creation event, and a publication mentoring programme. Network activities were supplemented by provision of digital resources (e.g. infographics) and member-only services (e.g. 'matchmaking' research interests for future collaboration). The network website provided a virtual space/hub of information, resource and service provision via news blog, and access-restricted member-only resources including training materials, membership directory, and other useful support resources for plant VBD research. The backbone of communications campaigns was a monthly e-newsletter providing news, information, resources and opportunities for members to connect, alongside a Twitter channel which shared network resources and opportunities, relevant research-related online content, and connected members with other relevant accounts of individuals or organisations.

Training provision and career development opportunities for members arose as deeper Africa-facing partnerships developed via regular discussions within the Management Board, supported by acquisition of supplementary quality-related GCRF funding from within the University of Bristol. Responsiveness and adaptability to external funding parameters and other factors (e.g. the COVID-19 pandemic) combined with seeking updated community needs and a creative approach enabled many events and activities to be pivoted to readily accessible online platforms. Adopting accessible virtual meeting platforms (primarily Zoom) seemed to be more accessible to junior network members as they could join using smart phones, and meeting recordings were adapted into video resources accessible to members via the website.

From the outset, the Network Team sought to create a welcoming, inclusive, supportive and friendly community, reflecting the motivations and values of founding members. This underpinned the ethos and mode of conduct of the network activities, implemented in the design and running of events, and the communicative style of campaigns.

Table 2: Gantt chart of CONNECTED Network activities.

Activity	Type	2018	2019	2020	2021
UK launch conference	In-person event				
Uganda launch conference	In-person event				
Pump prime funding (PPF) call 1	Individualised in-person/online activity				
Pump prime funding (PPF) call 2	Individualised in-person/online activity				
PPF 1 projects	Collaborative projects				
PPF2 projects	Collaborative projects				
Training Voucher Scheme round 1	Educational visits				
Training Voucher Scheme round 2	Educational visits				
T19 Training Grant Scheme	Educational visits/course attendance				
Introduction to Virus & Vector Diagnostics (BecA-ILRI, Kenya)	In-person training course				
Introduction to Virus & Vector Diagnostics (IITA, Nigeria)	In-person training course				
V4 Training Programme	In-person training course				
Bioinformatics Course Sweden	In-person training course				
Training Grant Scheme	Educational visits/course attendance				
Springboard to Impact Conference	Online event				
Communications Coaching	Online training course				
INEXTVIR Seminar Series	Online event				
CONNECTED Seminar Series	Online event				
Scientific Publication Mentoring Scheme	Individualised online				

METHODS

The CONNECTED Network began enrolling members via a website from November 2017 following a publicity campaign and targeted recruitment of existing connections: new members submitted an online form providing individual professional characteristics including country of work, institution, gender, level of experience/progression, and expertise. A member directory export in November 2021 showed demographic information was provided by 1,447 members (92%) at the time of enrolment. 980 members supplied ORCID identifiers and 328 members provided Twitter handles, the latter predominantly from Nigeria (82), Kenya (55), UK (44), Uganda (22).

We measured the characteristics of the social network formed by members co-participating in events each year. Measures of social network cohesiveness allowed us to assess convergent and divergent practices of members over time. We measured network density, transitivity, and mean eigenvector centrality, higher values indicating convergent behaviours, and mean path distance, diameter, mean degree centrality and mean betweenness centrality, higher values indicating divergent behaviours (Borgatti et al. 2018). We undertook OLS linear regression to examine the association between member characteristics, convergent and divergent behaviours and event participation, using a participant's eigenvector centrality in the co-participation network as the measure of closure (convergence) and betweenness centrality as the measure of brokerage (divergence).

Qualitative research methods were used to explore the personal experiences of network members to enrich the social network analysis by adding insight into elements that are typically difficult to quantify: 'nuanced, in-depth' accounts which could elucidate areas of complexity within network member's collaborations (Braun et al., 2021).

We conducted a qualitative study to discern how members understood and went about forming connections and collaborations, and to interrogate members' motivations, value systems, and understandings of collaboration. The study comprised a short survey and semi-structured interviews with key individuals identified in the network analysis as 'cores' and 'connectors' between different communities of expertise within the network. The survey consisted of five open questions linked to the interview schedule, issued to participants after attending a CONNECTED event. Thirty-seven members completed the survey representing various disciplinary backgrounds including plant virologists and entomologists from Burundi, Kenya, Rwanda, South Africa, Tanzania, The Democratic Republic of the Congo, Uganda, Zambia and Zimbabwe.

Nine interviews were undertaken with network members, who included academics and industry experts from Kenya, Nigeria, South Africa, The Republic of Benin, and the UK. Two interviews were with senior academics (Lecturer, Reader or Professor) and seven with ECRs. All interviews took place virtually and were assisted via interview schedules.

The qualitative data were supplemented with contextualizing information from the CONNECTED Network Managers, incorporating information from funder progress reports, MLE system findings, 'lessons learned' notes, and reflective conversations.

The authorship team convened a two-day in-person ‘retreat’ workshop to integrate insights from qualitative study and research context to develop the research questions. The ‘retreat’ facilitated discussions that enabled the qualitative findings to be interpreted as evidence for the research questions. Collectively thinking through the various aspects of the research context proved critical for finalizing the theoretical framework: framing conditions and types of community practices within the convergent/divergent activities; modes and styles of interaction at the individual and collective levels. This permitted a deeper understanding of the nuanced, micro-level influences of the network activities programme on emergent scientific collaboration and capacity.

FINDINGS

Between November 2017 and October 2021, 1568 individuals joined CONNECTED (no data were available for those leaving the network). Enrolment grew rapidly during the year from November 2018, following the second call for applications for PPF and first call for funded training (see Figure 2). New enrolments slowed thereafter. Upon enrolment, members were asked to list up to five areas of expertise in their own words. Normalised to make spelling and similar categories consistent, 4512 distinct categories were contributed, a mean of 3.1 per member. The most common categories were ‘Molecular Biology’, ‘Virology’ and ‘Bioinformatics’. Expert input from the CONNECTED Network identified those self-descriptions that could be meaningfully classified as expertise in plant virology/pathology (418), entomology (121) or both (154).

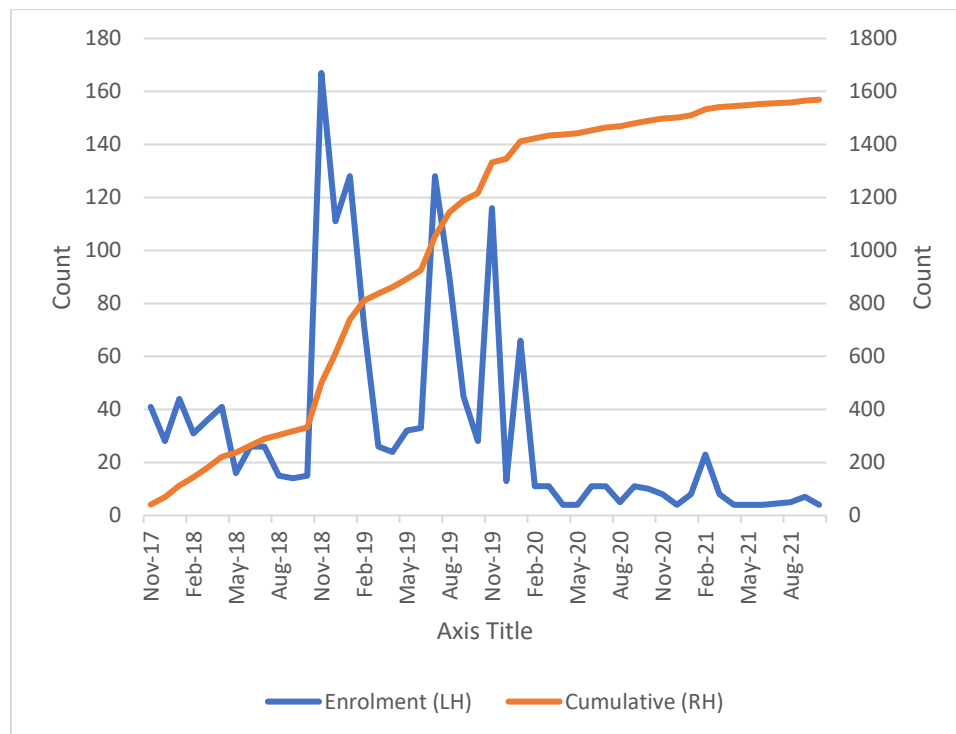


Figure 2. Monthly enrolment and cumulative membership.

Framing conditions

The conditions framing the operation of the network shaped the opportunities for and nature of interactions that were possible, and the depth of personal connections that could emerge. They also influenced the structure of the network activities programme by placing limitations on the type, scope, and sequencing of activities that were possible. Such conditions were established by a range of factors, categorized as follows (with examples from CONNECTED):

- 1) Regulatory structures including strategic and financial parameters of the funding award plus the governance structures put in place to guide and administer the network.
- 2) Technological and geographical parameters affecting the nature of interactions: technological platforms and tools used for interacting (in-person: private venues, university buildings, research stations; online: Zoom, MS Teams, Google drive), and geographical locations of interacting individuals (UK, SSA, global).
- 3) Entrenched societal orientations and multi-layer power imbalances between those who interact relevant to the production of scientific knowledge through collaboration. These can include epistemological, languages, theories and concepts, the 'development' frame, institutional resourcing, and practical arrangements.
- 4) Motivational ethos and interpersonal practices, including the attitudes and approaches, of those who both design and implement the activities, and engage in the interactions.

Qualitative findings provide evidence applicable to more than one of the conditions. For example, multiple participants mentioned that the administrative work of the highly skilled Network Team enabled success. This is relevant to both the regulatory structures in place alongside the motivational ethos and interpersonal ethos/practices of the team.

A major impacting factor on the conditions of the network which was not present at the start was the COVID-19 pandemic. This vastly altered the nature of interactions which could take place, influencing the modes by which convergent and divergent practices could operate: individuals were not able to interact in person, collaborative projects were abruptly paused with impacts manifesting across varied timescales in different countries. The operation of the network, however, was relatively resilient to the impacts of COVID-19 by way of embedded communications and ICT capacity within the Network Team. The pandemic also indirectly altered the technological parameters through which members could interact: the sudden need-driven movement to video conferencing (via tools such as Zoom) rapidly increased the functionality and accessibility of such tools to the global membership. It also influenced the acceptability of such approaches for more regular virtual connection and communication. The experience of the Network Team was such that this increased the accessibility of online events to ECRs who could use their smart phones to join events.

1. Regulatory structures

The priorities and objectives of both the funding call and the specific objectives of CONNECTED provided the overarching direction and structure for the evolving network. These set the terms and conditions

constraining all network activities: types of activities which could be implemented and the demographics of researchers eligible to receive funding. The priorities and objectives provided both opportunities and constraints: whilst a proportion of total grant funding was constrained to pump prime funding new projects, a large proportion could be allocated to a broad array of network activities as decided by the Network Team. The funding available and spend criteria supported convergence and divergence within the network and represented a key driver to join the network for ECRs and senior academics alike. As examples, convergence was provided via in-person conferences, and divergence through pump-priming new collaborative projects. For ECRs, divergence appears most impactful with pump prime funding and training grants allowing important connections to develop nationally and internationally, within and beyond their disciplines, and providing the valuable research experience and new skillsets pivotal to career progression. However, it also limited the extent of connections that could occur.

A strength of CONNECTED at the proposal assessment stage and for enabling future success and impact, was the prior establishment of an international group of experts to form the Management Board, and inclusion of costs for the Network Team, including designated project management, communications and administrative roles.

2. Technological and geographical parameters

The technological parameters governing interactions included the information and communications platforms available from the coordinating institution, and publicly, for enabling members to access network information and events, the project website for information and resource sharing and the membership directory. The Network Managers reported that available options and member feedback shaped the choice of platforms made by the Network Team for enabling accessible and inclusive participation, such as Zoom for online events and video conferencing, emails between small groups for sharing collaborative documents, and social platforms such as Twitter for broadcasting news and information, plus WhatsApp for peer group instant messaging. The project website was established as an independent site from the coordinating institution in a future-proofing move: an independent domain could be more easily transferred to alternative hosts and avoided institutional branding. Website hosting parameters were selected to ensure fast loading for international visitors.

Geographically, focusing all activities on SSA exerted a significant influence over the nature of the activities, processes and outcomes. It directly affected the cost and logistics of in-person events, the academic roles which could be assumed by partners within the PPF projects due to funder eligibility criteria, the digital platforms used for online events, and the design of digital resources for network members to ensure accessibility (such as provision of digital downloads rather than live streaming for training videos as this improves accessibility when internet disruptions are common). It increased the complexity and timeframes for establishing research contracts for PPF projects where funds were to be transferred to overseas partner organisations, necessitating resolution of financial issues raised by the fundamental differences in financial operation of UK-based and SSA-based institutions (payments in arrears possible versus in advance often required). It also necessitated completion of due diligence checks on overseas partners, which often took considerable time. Convening UK- and SSA-based researchers enabled international connections to be made within/between ECRs and senior academics,

necessitating development of greater cultural awareness, and bringing into operation entrenched inequalities and imbalances (see 3 below).

3. Societal orientations and power imbalances

Societal orientations and resulting power imbalances are both part of the conditions governing how the network could be set up and the practices employed in responding to and managing imbalances and inequalities emergent during activities. From a social network perspective, power imbalances are expected to manifest in differential engagement of individuals with events and other individuals within the network. Purposefully enabling research institutions in the Global North to collaborate with those in the Global South brings into play colonial architectures of power that determine power imbalance (Aboderin et al., 2023).

Table 3 presents the results of linear regression models of potential influences on event participation each year (see Tables A1 and A2 for further detail). It can be seen that UK nationality was positively associated with participation in 2018 and 2020 but negatively in 2021. Nigerian participation was also particularly evident in 2020. But no other national or gender effects were notable. Similarly, economic seniority was not associated with participation, while early career roles were in 2019 and 2021.

Table 3. Event engagement regression models

	2018 (1)	2019 (2)	2019 (3)	2020 (4)	2020 (5)	2021 (6)	2021 (7)
Male	-0.00107	0.00029	0.00031	0.00025	0.00027	0.00005	0.00013
Early Career Researcher	-0.00230	0.00288 *	0.00308 *	-0.00119	-0.00112	-0.00050	-0.00056
PGR/Student	-0.00228	-0.00080	-0.00077	-0.00076	-0.00109	0.00027	0.00019
Research Assistant/Fellow	0.00073	0.00084	0.00081	-0.00033	0.00002	0.00287 ***	0.00276 ***
Professor	0.00112	-0.00235	-0.00181	0.00176	0.00122	-0.00178	-0.00132
Nigeria	-0.00130	-0.00089	-0.00087	0.00116	0.00066	-0.00053	-0.00051
Kenya	0.00050	0.00062	0.00067	0.00079	0.00121	0.00035	0.00035
UK	0.00820 ***	-0.00154	-0.00154	0.00646 ***	0.00760 ***	-0.00175 *	-0.00134
Plant Pathology	0.00220 *	0.00332 **	0.00326 **	0.00270 ***	0.00350 ***	0.00167 ***	0.00166 ***
Entomology	0.00128	0.00121	0.00134	0.00071	0.00099	-0.00006	0.00004
Engagement Y-1		0.31050 ***		0.55398 ***		0.21545 ***	
Brokerage Y-1		1.40508	1.14295	0.29497	2.29607 ***	-0.10267	1.21427 ***
Closure Y-1			-0.11716 ***		0.06666 ***		0.10274 ***
Constant	0.0045 **	-0.00057	-0.00082	0.00213 *	0.00253 *	0.00046	0.00043
Observations	595	594	594	1,283	1,283	1,381	1,381
Prob > F	0.000 ***	0.000 ***	0.000 ***	0.000 ***	0.000 ***	0.000 ***	0.000 ***
R-squared	0.127	0.130	0.134	0.229	0.121	0.128	0.131
Adj R-squared	0.112	0.113	0.116	0.222	0.113	0.121	0.123

Sig: *** p<.000, ** p<.01, * p<.05

At the strategic level, the orientation of GCRF funding call (providing Official Development Assistance funding) initiated the project with a firmly 'development' frame: provision of funds by the Global North "with the promotion of the economic development and welfare of developing countries as its main objective" (UKRI Official Development Assistance GCRF Guidance). This established power imbalances in the orientation of activities, framing assumptions that researchers in the Global South need to be recipients of knowledge and expertise from the Global North. The Network Team mitigated against this by conducting community need analyses: workshop sessions asked the network members to identify and prioritise knowledge, skills and resources required by the VBD research community in SSA to achieve research goals.

It is important to note that CONNECTED's coordinating location in a Global North Institution enabled access to relatively large amounts of funding which were inaccessible to partner institutions from the Global South. While this funding enabled access to the network community and delivery of training which were reported as valuable to researchers who were Africa-based, it was also limiting in that training offerings were mostly one-directional with knowledge transfer instead of knowledge exchange. Networking events however enabled greater knowledge exchange between partners in the Global North and Global South. It also set the use of English as the language used for all central communications and events. Power imbalances were exerted by a lack of equitability in aspects of the funder eligibility criteria for collaborative projects initially preventing Africa-based researchers from assuming the Principal Investigator roles (subsequently rectified, see 'Practice outcomes reshape framing conditions' below) and in travel grants (PhD students ineligible, despite many SSA-based senior research scientists conducting PhD studies alongside research contracts).

The Network Managers observed power imbalances between UK and African researchers manifest within interactions within workshop groups, and hierarchies of power play out between ECRs and senior academics regarding ease of expression, communication and engagement of junior researchers during events and sessions. The Network Team did what they could to balance this where possible, for example by purposefully designing breakout groups to separate ECRs and seniors from the same institution. Early in the project, the Network Team learned that there are relative differences in the merit attached to academic titles in the UK compared to SSA: in the UK, titles mostly reflect academic achievement, whereas this is not the case in SSA research. Here, it is common for senior academics and highly experienced to not possess PhDs. As a result, to level the playing field, the Network Team chose to not default to use of academic titles when listing event participants.

Financial regulatory structures are linked to power imbalances between Global North and South research organisations. The Network Managers reported that institutions operate within markedly different financial systems, with inherently different requirements and expectations, particularly regarding payments in arrears versus advance for research work, inclusion of administrative support costs with project direct costs, and the ineligibility of indirect costs.

4. Motivational ethos and interpersonal practices

The characteristics, qualities and attributes of individual researchers within networks have been a significant factor in the network's development and intended impact. Table 4 reports increased social

network transitivity in events 2018-2020 and increased degree and eigenvector centrality in 2021. This demonstrates increased interaction among participants during the course of the programme.

Table 4. Member-event network cohesion by year

Year	Density	Mean Path Distance	Diameter	Transitivity	Mean Degree Centrality	Mean Eigenvector Centrality	Mean Betweenness Centrality
2018	0.014	3.423	8	0.646	0.03	0.09	0.001
2019	0.009	4.051	10	0.734	0.03	0.07	0.005
2020	0.017	2.059	5	0.987	0.03	0.06	0.004
2021	0.008	3.171	6	0.729	0.04	0.10	0.002

Note. Two-mode network cohesion calculated in UCINET 6.3

Transitivity here refers to the proportion of an event participant's coparticipants who also participate with each other in other events that year, which is a measure of clustering. Mean degree centrality is the number of event coparticipants per member, a measure of participation; this also increased. Mean eigenvector centrality is degree centrality weighted by the degree centrality of each coparticipant, an indicator of the core members of the network; this decreased, indicating greater engagement outside core participants. Mean betweenness centrality measures connections with participants otherwise less connected with each other, a potential indicator of interdisciplinarity or geographical brokerage; this was higher in the middle of the period than at either end.

The interviews indicate that interpersonal connections and dynamics within and between network members and the Network Team, particularly senior-junior researcher interactions, have been important in sharing experience, mentoring and consulting. Relational expertise, that is the capacity to empathetically inhabit another perspective in such a way that allows you to understand the sorts of questions and issues this perspective would bring to the situation (Edwards, 2005), appears to have been an important attribute of certain members within the network and team. It relates to the success of senior-junior interactions in sharing knowledge and expertise, but also in the awareness of cultural differences and power imbalances inherent in this sort of international endeavour. One senior academic interviewee said, regarding collaboration between senior and ECR academics from the UK and African countries, "it's happened multiple times, it's happened through the training that we've delivered obviously but that's more a one-way thing. That if I come as a trainer, I train the people that are trainees and it works that way, but we've also had collaborative work through the PPF, the pump-priming funding, where I've learnt... I hope they've learnt from me as well, into each other's speciality and to try to build new solutions."

The motivational and interpersonal ethos/practices of the Network Team facilitated evolution of the network in both convergent and divergent activities via practical service. The Network Managers reported supporting visa applications and immunisations advice. This involved exhibiting awareness and responsiveness to the needs of individuals and of groups. Additionally, the communications strategy and style employed by the Network Team to engage with members contributed to fostering a collaborative

environment which the Network Managers reported was echoed in member interactions with the Team during events and written communications.

Practice outcomes reshape framing conditions

The nature, number and type of interactions which take place during events reshape the framing conditions, being implemented through the collective behaviour of network members and the overarching governance of the Network Team and Management Board. Aspects of this manifested in subtle learnings and shifts in behaviour relating to academic orientations, power imbalances, interpersonal styles, cultural awareness, and the agency and determination of individuals, and in more intentional actions via a MLE system set up early in the project.

The Network Managers reported that, unusually, CONNECTED enabled reshaping of some of the financial parameters constraining the spend of funds for pump priming new research within the project duration. This emerged not from any given event, but instead from the collective experience of all vector-borne disease (VBD) networks in the portfolio funded by the same GCRF funding scheme. In the early stages of the VBD networks, it was the funder's policy that researchers based in OECD DAC-list countries in SSA were not eligible to be Principal Investigators on pump-priming awards. In the spirit of the aims of the GCRF funding call, the Directors of the VBD networks coordinated a joint effort to lobby the funders to change this, resulting in a shift in the approach allowed. This shift enabled SSA-based researchers to academically lead PPF projects (i.e. assume Principal Investigator status) – facilitating recognition of intellectual leadership where it was due – while continuing to require that an eligible UK HEI acted as the administrative lead.

Technology parameters for interactions were reframed as a result of learning from events: online event connections were often disrupted for SSA-based members. The frequency of this is highly variable and can be linked to power outages, representing an accessibility imbalance between Global North and Global South members. Some attendees mitigated this by paying to use dedicated internet modems, at additional financial cost to themselves. The increasing awareness of these issues by the Network Team following international online events and feedback from members led to the implementation of a more accessible design of knowledge-sharing events and resources. Specifically, downloadable information resources (such as training videos and booklets) were provided rather than relying on continuous web-based streaming, and pre-recorded presentations were shared during events rather than given live. This learning was critical to widening participation from SSA members in events and long-term access to information and knowledge resources.

While focused on SSA, the Network Team were aware of accruing members in non-African countries. An analysis of network member country of origin in 2022 led to a conscious change in the name of the network (from 'Community Network for African Vector-Borne Plant Viruses' to 'Community Network for Vector-Borne Plant Viruses') to recognize the global community that had developed. While this did not necessitate any change in region of focus for capacity building, it did affect alterations in branding and associated messaging.

Sequencing and dynamics within the network

The sequencing of in-person and online events and activities within the phased programme was an important factor in building collaboration and research capacity. Network Managers reported that the phased design was shaped by themes within the Theory of Change, and incorporated strategic need, considering the high-level region-specific requirements of the SSA context. It responded to the specific needs of the emerging community (via launch conference workshop outputs) and was adaptable to MLE findings alongside to both internal and external influences and opportunities. These include changes in working patterns, as a result of COVID-19, availability of new funding (such as new awards to support additional training activities), and shifts in the short-, and long-term funding landscape (such as the 2021 UKRI ODA funding cuts; UKRI ODA letter). The communications and engagement activities that supported the phased programme pushed information out to members, providing signposting to online content and resources as the sequence progressed, rather than requiring members to seek information themselves, thus providing an enabling mechanism.

Practices promoting convergent behaviours among participants in events

Convergence in the network was achieved via both in-person and online events: convergent behaviours are evident in the in-person launch conferences in the UK and Uganda in 2018 and both the online Springboard to Impact conference and specialist seminar series in 2020, indicated by the higher density of interactions reported in Table 4. All in-person and online conferences comprised talks, networking sessions and facilitated workshops. Table 4 demonstrates that the interaction among event co-participants was most dense in 2018 and 2020.

There were few barriers to engagement with the network as a virtual space: it was free to join, requiring only submission of a registration form. Network Managers reported that the initial membership emerged from strong existing connections with key academics, researchers, and stakeholders via the professional networks of the project leads. The in-person conference at the very start brought these together with extended relevant connections. Each conference had clear objectives: to convene the early members of the network from the UK and across SSA, enable them to interact and get to know each other to form early collaborative teams, identify priority research questions for pump-priming and research community needs for capacity building, plus developing skills in interdisciplinary working. The events also aimed to provide lasting awareness-raising resources (such as videos and interviews with experts) that benefit members. The Network Team targeted relevant experts for participation, and designed a tailored programme of talks, workshops and networking sessions to derive insight directly from the community that would shape the subsequent capacity building activities. The tailored programme also aimed to achieve inclusivity and reduce power imbalances, engendering a 'level playing field' for participants of different career stage and background: this was achieved by requiring all participants to give short 'flash' presentations, and by the Network Team setting pre-determined workshop groups. The Network Team also arranged most of delegates travel and hotel accommodation and provided expenses to cover additional attendance-related costs to enable equitable participation as far as possible, reducing financial and administrative barriers. The Network Team worked to ensure the

conferences to operate in such a way as to coax a fun and relaxed atmosphere of respectful and inclusive engagement around mutual motivations to facilitate collaborative connections. This approach appeared to be successful and as such informed the ethos of online communications via social media and e-newsletter campaigns, and indeed subsequent online events.

Network Managers reported that the design of online events, as for in-person events, aimed at enabling inclusive, equitable participation and generation of lasting resources to support the research community. The choice of virtual platform impacted accessibility and necessitated careful consideration in response to feedback from the community.

Interview findings indicate that the in-person conferences were generally considered as spaces of meeting and that broadly, the network represents a space of convergence for members. For ECRs, the network operated as a space to build professional and personal networks that could help with career progression, researcher collaboration, and impact/dissemination of work. Being a member enabled ECRs to gain access to important/relevant research they could not otherwise access and provided a space to receive vital training.

Practices promoting divergent behaviours among participants in events

Divergence practices within CONNECTED include both in-person and online interactions as well as the pump priming of new research projects, grants for training courses/educational visits, knowledge co-production events, specialised seminars, plus mentoring and coaching schemes. Network Managers reported that these activities were supported by the Network Team via provision of an online 'matchmaking' service, inviting network members interested in connecting with other members, either for collaborating on a PPF bid, or for other collaborative activities, to provide their interests and contact details which were then shared with other network members.

Table 4 reports the density of interaction among event co-participants was lowest in 2019 and 2021 and the average path distance and mean betweenness highest in 2019. These indicate years of greater opportunities for novel connections and combinations of contacts and brokerage between knowledge or geographical areas.

Interviews indicated that connections arising through education visits/courses (Training Vouchers Scheme) provided pivotal moments of convergence and connection-forming for many participants. In-person divergence activities were mentioned by multiple interview participants as being effective in developing connections, which were then supported/reaffirmed via WhatsApp group chats. Where only in-person events were mentioned as being spaces for connecting with others, interviews referenced various in-person and online training events as being impactful for developing participants research skills.

Interviews cited WhatsApp as being used by majority of participants to facilitate connection and collaboration over other social media platforms such as Twitter. For ECR and PhD students especially, the connections formed through the PPF projects and education training visits have been developed and nurtured via the facilitation of WhatsApp groups. For some participants, these groups continue to act as essential spaces to share their work, ask subject-related questions, offer peer-support and career

development opportunities. For many participants, these WhatsApp groups enable the facilitation of connection and collaboration.

DISCUSSION

The findings of the CONNECTED case study are generally consistent with the theoretical framework we utilise. There was clear evidence that framing conditions determine practices that shape the evolution of collaboration and some evidence that these outcomes in turn reshape the framing conditions. The limited period of the programme did not provide extensive examples of this feedback loop but there was clear learning and adaptation of practices. Interestingly, the extent to which this occurs is itself determined by the capacity of those involved to learn and adapt, a framing condition itself missing from our initial considerations. This is consistent with Sonnenwald's (2007) findings on the importance of framing conditions to collaboration and Archer's (1995) work on the coevolution of framing and outcomes.

There was clear evidence of distinct practices developed by the Network Team to encourage convergent and divergent interactions among members, partly shaped by the funding requirements (i.e. to pump prime new collaborative projects) and partly developed intuitively. Network Managers were motivated to bring members together inclusively to build collective identity, overcome inequalities and seed collaboration but also to initiate diverse specialised projects and training opportunities to build capacity. This supports Powell et al.'s (1996) findings that the *way* people connect is critical to ongoing interaction and the different communication needs at different stages of collaboration (Kraut et al. 1987; Sonnenwald 2007; Newell & Swan 2000).

These practices supporting the formation of an epistemic community over time highlights the value of long-term support for collaborative network initiatives of this kind that aim to increase scientific collaboration and capacity, particularly across disciplinary boundaries. The approach used by CONNECTED demonstrates how it is possible to intentionally develop a core community of technical and experiential expertise, alongside the brokerage across more diverse knowledge areas which enables the transitioning from knowledge heterogeneity towards knowledge integration necessary to lead to interdisciplinarity and innovation (Zhang, 2023). This adds valuable insight to augment the literature regarding the effectiveness and operation of collaborative research networks. It complements recent work illustrating the increasing diversity and equity in co-authoring that can arise from long-term collaborative networks (Baillie et al., 2021) and goes beyond methodologies for enabling interdisciplinary research (Tobi and Kampen, 2018) which commence once collaborative teams have formed.

Particularly in the field of plant science, it complements and goes beyond the findings of, to our knowledge, the only other published study of a plant-focused collaborative network, the GARNet Network (Parry et al., 2020). Parry et al. highlight factors contributing to the success of their national collaborative network which our study corroborates, including establishing an advisory board for good governance, gender balance in the leadership and governance structures, provision of designated project management, initial incentivization of community participation, securing additional funds to enable community-facing activities, and engaging ECRs. While their study highlights the broad and

extensive impacts of their network, it does not identify how collaborative relationships emerge from activity types.

CONCLUSIONS

Research networks have become a popular mechanism within national and international funding landscapes to achieve enhancements of scientific research community capacity and capabilities. However, evidenced methodologies underpinning network approaches have been lacking. This paper provides evidence to underpin the efficacy of collaborative networks in increasing scientific collaboration and research capacity, including facilitating interdisciplinarity, when they adopt certain operational characteristics. Our study demonstrates that a phased programme of in-person and virtual convergence and divergence activities which includes opportunities for participation in collaborative projects/activities and individualized interactions can lead to greater scientific collaboration and interdisciplinary research capacity, when set within the appropriate framing conditions. For CONNECTED, this provided the backbone for measurable widespread collaborative outcomes in terms of knowledge and information sharing and integration, beyond the narrower range of high order collaborations such as co-authorship.

Learning from the examples provided by the CONNECTED network, we offer a series of practical suggestions for research funders/supporters in adopting more structured, intentional approaches to future collaborative network-based approaches to ensure maximal realization of benefits from investment:

1. Give consideration to the objectives of the collaboration, particularly the types of multidisciplinary research capacity and diversity of membership sought.
2. Make use of identified combinations of expertise to seed accelerated consolidation of networks and expansion into other regions, as appropriate.
3. Actively broker connections that meet these objectives, including diverse combinations of research expertise, to more robustly achieve diversity in collaboration, bridging disciplines towards interdisciplinarity.
4. Acknowledge and promote the value of online collaboration and individualized online interactions as an outcome and a contributor to the emergence of collaboration and capacity around in-person events.
5. Develop mechanisms to engage members in individualized online interactions such as following, sharing and referring to other members' information and insights. This can be achieved by including social media handles on conference IDs and delegate lists (with appropriate permissions), organising befriending drives around themes or expertise.
6. Design specific engagement strategies for groups that make less use of the available collaborative opportunities, including online tools.
7. Physically locate consolidating events in regions targeted for expansion: engaged members go on to engage with further activity. So, to expand in a region a foothold needs to be established.

8. Track member engagement in various forms of scientific collaboration over time, supplemented by qualitative research into collaborative goals and drivers of interdisciplinarity, to provide an evidence base for further refinement of initiatives.

Future research could usefully extend this work by providing additional robust case studies that illustrate and exemplify the feedback relationships between collaborative network outcomes and the framing conditions for operation. Investigating the role of the attitudes, behaviours and learning/adaptation capacity of those who coordinate collaborative networks in impacting network outcomes will further illustrate the importance of intentional management for achieving goals and realizing benefits from investments.

APPENDIX

Table A1. Descriptive statistics for variables used in linear regressions

Variable	Obs	Mean	Std. dev.	Min	Max
Male	1,447	0.64409	0.47895	0	1
Early Career Researcher	1,460	0.79589	0.40319	0	1
PGR/Student	1,568	0.16518	0.37146	0	1
Research Assistant/Fellow	1,447	0.10366	0.30493	0	1
Professor	1,447	0.03248	0.17734	0	1
Nigeria	1,450	0.27655	0.44745	0	1
Kenya	1,450	0.12276	0.32827	0	1
UK	1,450	0.09103	0.28776	0	1
Plant Pathology	1,568	0.36480	0.48153	0	1
Entomology	1,568	0.17538	0.38042	0	1
Engagement 2018	613	0.00432	0.01208	0	0.08108
Engagement 2019	1,346	0.00223	0.00926	0	0.08108
Engagement 2020	1,501	0.00443	0.01224	0	0.10811
Engagement 2021	1,568	0.00172	0.00846	0	0.10811
Closure 2018	613	-0.01209	0.03314	-0.1791	0.00000
Closure 2019	1,346	0.00454	0.02688	-3.42E-08	0.27824
Closure 2020	1,501	0.00822	0.02183	0	0.06904
Brokerage 2018	613	0.00003	0.00022	0	0.00198
Brokerage 2019	1,346	0.00007	0.00090	0	0.02441
Brokerage 2020	1,501	0.00008	0.00067	0	0.01492

Table A2. Matrix of correlations among variables

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
(1) Male	1.00																			
Early Career																				
(2) Researcher	0.07	1.00																		
(3) PGR/Student	0.01	0.14	1.00																	
Research																				
(4) Assistant/Fellow	0.02	0.08	-0.15	1.00																
(5) Professor	0.04	-0.34	-0.09	-0.08	1.00															
(6) Nigeria	0.05	0.20	-0.03	-0.01	-0.06	1.00														
(7) Kenya	-0.07	0.09	0.00	-0.07	-0.08	-0.18	1.00													
(8) UK	-0.09	-0.38	-0.03	0.11	0.13	-0.23	-0.16	1.00												
(9) Plant Pathology	-0.08	-0.10	-0.01	0.05	0.07	-0.13	0.12	-0.07	1.00											
(10) Entomology	0.00	-0.14	-0.11	0.03	0.08	-0.17	-0.03	0.09	0.13	1.00										
(11) Engagement 2018	-0.08	-0.22	-0.09	0.05	0.10	-0.14	-0.02	0.30	0.10	0.11	1.00									
(12) Engagement 2019	-0.02	0.05	-0.04	0.06	-0.04	-0.07	0.05	0.00	0.16	0.08	0.30	1.00								
(13) Engagement 2020	-0.02	-0.11	-0.09	0.04	0.04	-0.05	0.04	0.17	0.19	0.07	0.42	0.50	1.00							
(14) Engagement 2021	-0.01	-0.02	-0.04	0.18	-0.05	-0.07	0.07	-0.02	0.18	0.03	0.23	0.40	0.37	1.00						
(15) Engagement 2022	0.09	0.23	0.09	-0.06	-0.07	0.14	0.02	-0.30	-0.11	-0.09	-0.98	-0.31	-0.40	-0.24	1.00					
(16) Closure 2018	-0.01	0.08	-0.04	0.07	-0.04	-0.01	-0.03	-0.08	0.06	0.06	0.06	0.46	0.19	0.33	-0.06	1.00				
(17) Closure 2019	-0.02	-0.07	-0.05	0.04	0.02	-0.05	0.07	0.08	0.21	0.02	0.33	0.44	0.87	0.40	-0.34	0.22	1.00			
(18) Closure 2020	-0.05	-0.10	-0.05	0.07	0.05	-0.07	-0.05	0.17	0.06	0.07	0.64	0.21	0.26	0.24	-0.63	0.03	0.22	1.00		
(19) Brokerage 2018	0.04	0.04	0.00	-0.02	-0.02	0.03	-0.01	-0.03	0.04	0.03	0.10	0.46	0.23	0.08	-0.11	0.32	0.20	0.08	1.00	
(20) Brokerage 2019	-0.06	-0.04	-0.06	0.07	0.01	-0.01	0.01	0.14	0.06	0.08	0.28	0.36	0.65	0.24	-0.27	0.06	0.36	0.25	0.14	1.00

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