LITERATURE REVIEW ON FUNDING AND COMPOSITION OF INTERDISCIPLINARY RESEARCH AND INNOVATION TEAMS

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SCIENCE DIPLOMACY

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INTRODUCTION

This report presents the findings from a comprehensive review of the literature on drivers and enablers of funding, composition, and leadership of interdisciplinary research and innovation teams. The report has been commissioned by the Danish Council for Research and Innovation Policy as part of the Council's ongoing work on diversity and interdisciplinarity, which addresses several challenges of funding, evaluation, and leadership in interdisciplinary research and innovation programmes.

The review was undertaken from April through June 2021 and was concluded by the beginning of July 2021. The report includes findings from 50 articles, chapters, reports, evaluations, and position papers published in peer reviewed journals as well as policy literature. Findings and conclusions presented in this review are the outcome of a robust sample of literature, aligning qualitative and quantitative approaches, and covering several dimensions and factors for success and failure of interdisciplinary research and innovation. Building on this work, it is possible to acquire in-depth knowledge about the contextual drivers, values, and barriers of diverse interdisciplinary research and innovation teams with a special focus on funding, evaluation, and leadership.[1]

For the purpose of this review, we have applied a number of selection criteria to identify relevant contributions and information. By focusing on 50 specific publications, we can determine comprehensive recommendations and observations in the literature as well as develop summary conclusions such as common characteristics, trends and topics. Items included in the review has been sampled by selecting authoritative and well-cited contributions from peer reviewed literature (informed by citation analysis using Google Scholar) and influential and high-level policy reports, evaluations, and position papers (grey literature).

The review is structured in two parts.

Part One addresses how research funding organizations describe and cultivate interdisciplinary and diverse projects based on content retrieved from selected evaluations, position papers, and academic literature etc. (outside-in perspective). Contributions included in this part address different "steps" from strategy, calls for proposals, evaluation of proposals, criteria for funding, follow-up, and final evaluation of interdisciplinary research. Part Two addresses how the academic and grey literature describe preconditions for successful interdisciplinary and diverse research teams based on studies of research management, research organisation, and team composition (inside-out perspective).

All included contributions address one or more of the following topics: inclusion, diversity, equality, integration, time scales, mentoring, evaluation, principles of funding, academic leadership, team science, team construction, collaborative competences, psychological safety, knowledge sharing, on-boarding, engagement, and impact.

[1] The purpose of this review is to provide an overview of the available literature without producing a complete or representative summary. The review is useful for answering broad questions, such as "what information has been presented on preconditions for successful interdisciplinary research teams" and for gathering and assessing information prior to conducting a systematic review.

SUMMARY AND KEY FINDINGS

- **Context and scope**. Interdisciplinary research and innovation have become a major trend in science policy and research funding. Most countries, universities, and funding organisations have dedicated instruments to support interdisciplinary research teams. There is a vast academic and policy literature describing key mechanisms for funding, organising, and evaluating interdisciplinary research.

- **Complexity**. Interdisciplinary research is a mode of research that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from multiple disciplines to solve complex, scientific or societal problems. At the same time, interdisciplinarity is a mode of organising and leading diverse individuals and teams to work together across boundaries based on collaborative problem-solving and shared knowledge.

- **Institutional change**. Several studies urge policymakers and funding agencies to take a greater look at the research and innovation eco-system in which they are making investments. Instead of providing funding for specific interdisciplinary programmes, policymakers should support and incentivise universities to build capacity in interdisciplinary research, e.g., by supporting interdisciplinary career paths and integrate interdisciplinarity in education and training.

- **Funding instruments**. The review finds that funding agencies should play a proactive role in stimulating interdisciplinary research and actively promote integration and collaboration, e.g., by fostering cross-council collaboration and peer review. Successful interdisciplinary research starts with the internal organisation of the funding agency itself. The degree to which interdisciplinary grant-holders are effective is influenced by the scope and flexibility of the funding programme.

- **Time scales**. The review finds that it is necessary to provide short-term as well as long-term funding for interdisciplinary science. Seed funding is important as interdisciplinary research teams need to experiment with new collaborative approaches and find new partners. Long-term funding is necessary to support successful interdisciplinary research groups, e.g., by enabling academics to establish new integrative research fields, supporting research infrastructure, training, and partnerships.

- **Integration and facilitation**. Interdisciplinary projects and programmes need to include "knowledge brokers" that are able to connect otherwise isolated disciplinary experts and help to diffuse innovative ideas within a network. In addition to traditional academic expertise, interdisciplinary teams require experts in knowledge integration and implementation that represent an emergent form of expertise beyond disciplinary excellence.

- **Interdisciplinary excellence**. Evaluating interdisciplinary excellence require peer reviewers and funding agencies to depart from strictly monodisciplinary quality criteria and include organisational, leadership, and communication skills in the assessment. Several contributions point out that it is often not sufficiently clear what constitutes interdisciplinary excellence, and that funding agencies should adopt evaluate criteria based on the mission and purpose of the relevant funding programme.

- **Diversity**. Several contributions emphasize that diversity is a crucial condition for innovation, and that fostering greater diversity in scientific teams contribute to excellence and frontier research. Diversity is seen both as a normative and functional value. Cognitive diversity in

groups matters for their ability to perform well in creative tasks. Diverse teams have superior team performance on measures such as innovation, collaboration, and critical thinking. Different problem-solving approaches and complementary skills serve to promote creativity and debate, ensuring more alternatives are considered and additional rigor is applied when identifying solutions.

- **Inclusion and trust**. The review finds that interdisciplinary research should be driven by an attempt to create an organisational culture founded on, and advanced by, a shared commitment to open communication, mutual respect, and trust. Trust is built by leaders who maintain fairness in the recognition and reward of team members' contributions. Therefore, leaders' personal qualities, including trustworthiness, transparency, and openness to different approaches and perspectives, are instrumental to encourage and influence team members.

- **Team size**. Available evidence suggests a positive correlation between team science and publication outcomes within certain thresholds. Some evidence indicates that larger teams often are more productive and impactful but also that larger teams may be vulnerable to conflicts and fragmentation. Team size has also been found to be associated with other types of outcomes. For instance, studies have found that smaller teams are more likely to generate new disruptive ideas whereas larger teams are more likely to further expand breakthroughs in new directions.

- **Leadership**. Inclusive leadership and proactive management are crucial elements throughout an interdisciplinary project. Focusing on network- and community-building in the early stages of a research initiative contributes to the degree and extent of integration and, thus, the synergy and impact achieved. The review finds that successful team leaders need the ability to bridge between different cultures and build consistence and coherence in the team over time.

OVERVIEW OF THE FIELD

Interdisciplinary research and innovation have become a major trend in science policy and research funding. Most countries, universities, and funding organisations have dedicated instruments and infrastructures to support interdisciplinary research. At the European level, the EU Framework Programmes for Research and Innovation, such as Horizon 2020 and Horizon Europe, have become major drivers of interdisciplinary science and technology (NAS 2005a, LERU 2016, EUA 2019, EASSH 2021).

While interdisciplinarity has become an obligatory component in most science and innovation policies, "the interdisciplinary turn" has been associated with significant challenges. Among other things, it continues to be a challenge to integrate researchers across scientific fields, such as natural, human, social, health, and technical sciences (Vienni et al. 2020, Bozeman & Boardman 2014, Boone et al. 2020, Bammer 2020, EASSH 2021). New models of evaluation, leadership, and team construction in interdisciplinary projects are continuously tested and challenged (Stokols et al. 2008, Broham et al. 2016, Bennett et al. 2018, Banal-Estañol et al. 2019). In this review, we find several important contributions that shed light on central aspects of interdisciplinary research funding, implementation, and evaluation including functional and demographic diversity, modes of integration, and guidelines for team composition and leadership.

A general observation from the review is that there are certain gaps between the policy literature and the academic literature on interdisciplinary research management. The policy literature does not often refer to academic research on interdisciplinarity and often contains an implicit assumption that successful interdisciplinary collaborations emerge from the availability of funding. As such there seems to be a potential for closer interaction and learning among policymakers and funding agencies interested in interdisciplinary research and innovation, and scholars who are studying these processes. While there is a wealth of knowledge available across the academic literature, its uptake does not appear to be widespread among policy institutions.

Furthermore, it is worth noticing that the academic and grey literature on interdisciplinary research is marked by considerable heterogeneity. "What is interdisciplinary research" and "what is the role of interdisciplinarity in the advancement of science" are questions that have triggered many conversations and raised several dilemmas. Despite heterogeneity, most contributions agree on the frequently cited definition of interdisciplinarity adopted by the US National Academy of Sciences (2005b).

> 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 (NAS 2005, 2).

Even in the face of this widely cited source for understanding interdisciplinarity, it is important to acknowledge the significant variations of interdisciplinary research practices. Interdisciplinary research and innovation cover a broad variety of activities, from joint problem-solving in innovation teams to answering deep scientific questions and developing emergent technologies across traditional fields of specialisation (Vienni et al. 2019).

For the purpose of simplicity, we will use the term *interdisciplinarity* as a generic reference for research that is driven by collaboration across disciplines (an alternative candidate for such a generic term is cross-disciplinarity). By doing so, we are setting aside consequential debates in philosophy of science regarding the nature of interdisciplinary research (e.g., the role of representation, interoperability, commensurability etc). and focusing instead on organisational and contextual drivers of team science.

However, it is worth noting that the literature is operating with several different notions of interdisciplinarity, which need brief clarification. According to Stokols et al. (2008) the three leading definitions are:

- **Interdisciplinarity** is commonly understood to be an interactive and integrative process in which researchers work jointly to address a common, "complex" research problem. In many cases, team members not only combine concepts and methods drawn from different fields, but work to integrate their divergent perspectives.

- **Multidisciplinarity** is a process in which scholars from disparate fields work independently or sequentially, periodically coming together to share their individual perspectives for purposes of achieving broader-gauged analyses of common research or societal problems. Participants in multidisciplinary teams remain anchored in the concepts and methods of their respective fields while working towards joint solutions.

- **Transdisciplinarity** is a process in which scientists and non-scientists (practitioners, stakeholders, entrepreneurs) work together in partnerships representing different sectors of society over extended periods to develop joint solutions to real-world problems, for instance by using methodologies such as co-creation, co-production, or co-design.

It is evident from these definitions that there is considerable variation between forms and practices of cross-disciplinary team science. But there are also similarities. A widely accepted characteristic is the idea that interdisciplinary teams strive to combine and, in some cases, to achieve **integration** of concepts, methods, theories, techniques and approaches drawn from different disciplines (Stokols et al. 2008, 78).

Interdisciplinary research is an integrative process in which researchers work jointly to develop and use a shared conceptual framework that synthesizes and extends discipline-specific theories, concepts, and methods to create new models and languages to address a joint research problem. A key goal of interdisciplinary funding programmes, for example, is to bridge the perspectives of different fields through the collaborative development of integrative conceptualizations, methodologic approaches, and training strategies (Stokols et al. 2008, 79).

In this report, we will not evaluate the strengths and weaknesses of the different typologies but simply refer to inter-, multi-, and transdisciplinary research as **interdisciplinary** (or cross-disciplinary) research. We will assume that interdisciplinary initiatives and programmes in general have as an explicit goal to integrate theories, methods, strategies, and problems drawn from different scientific fields to address complex scientific or societal challenges (Stokols et al. 2008).[2]

This leads us to a final introductory remark. It is worth emphasising that one of the main policy drivers of interdisciplinary research programmes and initiatives is the assumption that real-world problems are not confined to disciplinary boundaries. Societal challenges and missions call for research and innovation that *transgress* established disciplinary silos (Lyall et al. 2013, Bozeman & Boardman 2013, Huutoniemi 2010, Bennett et al. 2018, Agrawal et al. 2020, Bammer et al. 2020, Ding et al. 2020, Deutsch et al. 2021, EASSH 2021). This is indeed a strong driver of interdisciplinary research funding, evaluation, and implementation.

[2] Other terms have been suggested to characterize the central idea of cross-disciplinary research, such as "team science", "collaborative research", "integrative knowledge production", "convergence", as well as "de-disciplinarity", "post-disciplinarity" and "anti-disciplinarity". However, it is outside the scope of this report to include contributions covering the entire spectrum of conceptual and empirical models of cross-disciplinary research, and we will be using these terms interchangeably (while acknowledging that each term can be contested).

Interdisciplinary research and team science has the potential to generate novel insights and new methodologies that no individual discipline can produce. This is a valuable resource in contemporary knowledge economies as complex problems of, for example, climate change, food security, or digitalisation become more pressing. The ability of public sector research funding agencies to deliver solutions to such challenges increasingly requires integration across disciplines, as well as involvement and engagement of public and private stakeholders and partners (Lyall et al. 2013).

PART ONE

Part One addresses how research funding organizations describe and cultivate interdisciplinary and diverse projects based on content retrieved from selected calls for proposals, evaluations, position papers, and academic literature etc. We call this perspective "outside-in" since it provides an understanding of the ways in which framework conditions, such as funding instruments and evaluation schemes, are influencing the research and innovation process from the outside.

In Part Two we take a closer look at the inside-out perspective, i.e., the ways in which research is organized and managed and ultimately creates new knowledge and breakthroughs. In preparing this literature review, we noticed that there are many more contributions available regarding Part Two than Part One. While researchers (on research) are granted access to case studies, interviews, focus groups, and themselves are developing conceptual models of interdisciplinary research, they do not to the same extent have access to funding decisions and peer review mechanisms (with significant exceptions).

To make up for this lacuna of scholarship, we have included several publications from the grey literature on research funding, research assessment, and research evaluation (e.g., DMHES 2013, DMHES 2014, DGF 2018, EUA 2019, LERU 2019, NAS 2005a). In these contributions we find significant observations, assumptions, and theory-development about the nature of interdisciplinary research funding and its consequences for the organisation and development of science. Therefore, in Part One we combine grey literature with scientific literature on the nature of interdisciplinary research funding and evaluation (e.g., Huutoniemi 2010, König & Gorman 2010, Bloch & Henriksen 2013, Lyall et al. 2013, Bromham 2016, Banal-Estañol 2019).

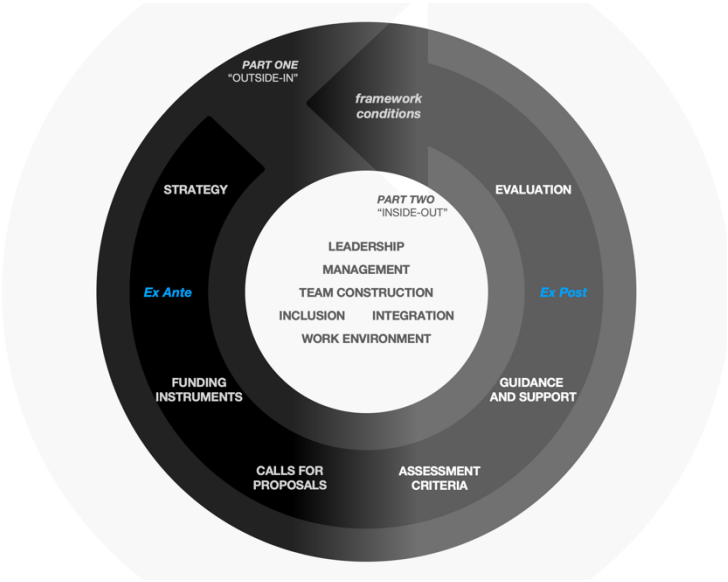

Figure 1. Part One & Part Two

Contributions included in Part One address different steps from strategy, call for proposals, evaluation of proposals, criteria for funding, models of academic leadership and final evaluation of interdisciplinary and diverse research outcomes. We have divided the analysis into sections dedicated to each of following **topics**:

1. Principles of funding interdisciplinary research
2. Evaluation of interdisciplinary research
3. Assessing the diversity of research teams
4. Time scales of interdisciplinary research
5. Impact assessment and pathways to implementation

1.1. Principles of funding interdisciplinary research

Research funders constitute important drivers of interdisciplinary research and innovation and play a number of essential roles. The literature contains several organisational steps that should be taken to promote and support collaborative research and integration of interdisciplinary research initiatives (Lyall et al. 2013, Ding et al. 2020). Awareness of these critical processes can benefit funders as well as practitioners if interdisciplinary research is to achieve its full potential.

This section builds on the existing literature on research funding structures that shape interdisciplinary programmes and summarizes the literature by providing principles for interdisciplinary programmes. Some of these principles may be applicable to those managing and implementing interdisciplinary projects of different scales.

Before continuing, we may start by asking if it is possible to expose the best ways to build institutional capacity and funding support for interdisciplinary research? Interdisciplinary research is realised at many different levels and in many different contexts. What works well in one context may not work in others. Paying attention to context, mission, outcomes, time scales, and scope of research programmes all matters when funding and reviewing interdisciplinary research (Vienni et al. 2020).

With some exceptions, funding agencies are reluctant to consider interdisciplinarity as a goal in itself. Rather, interdisciplinary research and innovation are seen as means to "achieving desired scientific, training, and translational goals" (Stokols et al. 2008, 84). Among these goals are two major funding drivers: one is the ability to solve *scientific* problems by integrating expertise from different disciplines, and hence produce breakthroughs, discoveries, and new technologies that no individual discipline is capable of realising. The second is the ability to solve complex and interconnected *societal* problems, which are not confined to academic specialities or disciplinary boundaries, such as global warming, cancer, heart disease, inequality, social cohesion etc. (Stokols et al. 2008).

The past two decades has witnessed a surge of interest and investments in interdisciplinary research programmes. Ambitious initiatives to promote cross-disciplinary collaboration in research and innovation have been launched by several public agencies and private foundations (Stokols et al. 2008, Lyall et al. 2013, Banal-Estañol et al. 2019, Blythe & Cvitanovic 2020, Blythe & Cvitanovic 2021, DMHES 2019, DFG 2016). Research funders have an important role to play in framing calls for interdisciplinary proposals and developing rigorous evaluation processes for both interdisciplinary proposals and, later, for evaluating the output and impact of funded projects.

> Decisions that funders make and the intention behind funding calls have a major impact on how interdisciplinary research is shaped, the extent of integration, and ultimately its effectiveness (Lyall et al. 2013, 67).

The literature generally divides the role of funding agencies into two distinct responsibilities: (1) activities that take place *before* grants are allocated (*ex ante*), e.g., investment strategy, calls for proposals, instructions for applicants, design of review criteria, instruction of assessment panels, etc. And (2), activities that take place *after* grants are allocated (*ex post*), e.g., follow-up, progress reports, interim evaluation, guidance and support for leadership, annual reporting, evaluation of programme outcomes etc.

Ex ante principles

Vienni et al. (2020) start by encouraging policymakers and funding agencies to take a greater look at the research and innovation eco-system in which they are making investments. Instead of channelling funding for specific interdisciplinary programmes, "policymakers should support and incentivise universities to build capacity in interdisciplinary research" by taking steps to "de-risk interdisciplinary career paths and integrate interdisciplinary research into education and training at an early stage." Funding agencies, according to Vienni et al. (2020) have a specific responsibility in cultivating a productive dialogue with universities, so that investments in interdisciplinary research are aligned with incentives, rewards, and career paths from the start.

DMHES (2019) presents the outcome of an independent evaluation of Innovation Fund Denmark and its funding schemes, including interdisciplinary programmes. The evaluation notices the importance, among other things, to set out clear rules for applications, informing applicants of the review process and final decision, and providing comprehensive information about calls, criteria, and assessment panels etc. The evaluation does not speculate about specific instructions for applications but advocates openness and transparency both during calls for proposals and in the evaluation process as a means of encouraging research and innovation teams to develop novel ideas.

Lyall et al. (2013) investigates how seven UK research councils with different funding instruments have stimulated varying levels of interdisciplinary integration and outputs. The study focuses on the design of interdisciplinary programmes and recommends that funders explicitly decide and communicate "the appropriate locus of interdisciplinarity". For example, teams of researchers may host cross-disciplinary meetings and seminars, they may publish together, they may integrate methods, models, and approaches, they may develop truly cross-cutting results, solutions, and technologies. But, according to Lyall et al. it is helpful if the funding agency indicates what type of interdisciplinary research that is relevant for the programme, and "think through the implications of which level(s) are to be the chief platform for interdisciplinarity" (Lyall et al. 2013, 66). Such guidance will make it easier for applications to produce suitable proposals, and it will guide the research design and team construction in the early phases of the research.

> Our research found that successful programmes had taken deliberate steps throughout to achieve integration and coherence. In particular, they had considered how best to tailor the design and implementation of such activities at the start of a particular programme through, for example, seed-corn funding for small starter projects, early workshops and/or other activities that might help to build and consolidate collaborations (Lyall et al. 2013, 66).

According to empirical results obtained in their study, Lyall et al. (2013) concludes that funding agencies should play a proactive role in stimulating interdisciplinary research and actively promote integration and collaboration, especially when programmes require cross-council collaboration. Successful interdisciplinary research according to this study starts with the internal organization of the funding agency itself: "funders' own structures and procedures should reflect good practice in the support of interdisciplinarity" (Lyall et al. 2013, 67). The degree to which interdisciplinary research teams are effective "is influenced by the setting up, focus and agenda of an interdisciplinary investment" (Lyall et al. 2013, 68).

Lyall et al. also recommend as a general principle that funding is "flexible", to allow time and space for projects and programmes to evolve and realise their full interdisciplinary potential. Therefore, funding needs to include investments in less visible processes – such as matchmaking activities, seed-corn support, team-building interactions, network- and community-building. Similar to Vienni et al. (2020), examined above, Lyall et al. suggest that funding agencies should play an active role in promoting

"organisational learning" in universities, that is, engage in dialogue with universities about how to support long-term capacity-building for interdisciplinary research and continue to embed, integrate, and support interdisciplinary research teams after external funding has ended (Lyall et al. 2013, 70).

Ding et al. (2020) provides practical actions for funding interdisciplinary health research. As a general principle the study highlights "the value of institutional seed money to initiate cross-disciplinary research projects" (p. 8). Instead of announcing funding calls for large-scale research projects with the expectation that successful teams will assemble organically, Ding et al. suggests that funding agencies should play a more proactive role in team construction and provide seed funding for small-scale collaborations to explore the potential of their research agenda and enable "early-career researchers to become co-principal investigators" (p. 9).

> Seed funding is important as cross-disciplinary research takes time and groundwork, and research teams with collaborative experience are more likely to secure funding and deliver outputs in the longer term (Ding et al. 2020, 9).

Ding et al. recommends that funding agencies adopt a "flexible, hands-off management style" which allows for creative solutions. Short-term grants can allow for group formation and testing of initial ideas. Long-term grants (more than three years) can support large-scale research collaborations and provide time to define shared interdisciplinary research problems. Funders are in a unique position to **empower** cross-disciplinary integration in funding calls, to commission research on cross-disciplinary communication and coordination, and to allow for flexible review processes, recognizing that cross-disciplinary research projects need their own project-specific metrics or review process" (Ding et al. 2020, 9).[3]

Ex post principles

Banal-Estañol et al. (2019) encourage funding agencies to take responsibility for actively supporting interdisciplinary research groups by adopting appropriate evaluation methods and criteria (p. 1825). This is particularly important when assessing the outcomes and impact of interdisciplinary research. Some outcomes may be published in traditional journals whereas other outcomes need to be assessed in their own right, for example contributions to policy, industry, or media. This diversity of outcomes and products need to be considered both in ex ante and ex post evaluation of interdisciplinary projects.

Stokols et al. (2008) support a context-sensitive evaluation model. They argue that "the quality of scientific work may be defined differently in the context of interdisciplinary team initiatives than in monodisciplinary projects (p. 80). A major challenge, therefore, is for funding agencies to specify the dimensions of "program effectiveness" or "success" as they pertain to team science initiatives. For instance, traditional criteria of scientific excellence include conceptual originality; methodologic rigor (e.g., validity and reliability of empirical findings); and the quantity of research outputs produced, such as peer-reviewed publications. In the context of interdisciplinary research initiatives, the scope of interdisciplinary integration (e.g., the development of integrative conceptualizations and methodologic approaches, the development of training programs bridging two or more fields, the emergence of new hybrid fields of inquiry) are important facets of collaborative success and must be considered in final evaluation.

Lyall et al. (2013) suggest that funding agencies take even more radical steps to actively support interdisciplinary integration among their grant-holders by "running events organised by the programme

[3] Peer review and evaluation are examined in section 1.2.

directorate" shifting the focus to stimulating learning as the teams mature (p. 66). According to this study, most of the success of interdisciplinary teams is dependent on the active involvement of funding agencies to foster "interdisciplinary integration" e.g., by "encouraging project teams to develop other forms of cross-cutting activities" to learn from different projects or themes across the wider instrument or agency. According to this framework, the funding agency should take responsibility of inviting grant-holders to meet, stimulating peer learning, and providing best practices for interdisciplinary project management and collaboratives skills.

Finally, Bromham et al. (2016) investigate the apparent "paradox of interdisciplinarity", i.e., the fact that interdisciplinary research is often encouraged at policy level but poorly rewarded by funding instruments. In their study, Bromham et al. clearly states that "funding agencies play a key role in shaping interdisciplinary research, with both positive influence, such as dedicated programmes for interdisciplinary projects, and negative impacts, as perceived biases can discourage submission of interdisciplinary proposals to open funding calls" (Bromham et al. 2016, 684). To mitigate this situation, research councils and foundations need to carefully think through the chain of decisions – from strategy to call for proposals, criteria for funding, peer review, models of leadership and final evaluation of research outcomes.[4]

It is clear from most of the contributions within this topic that interdisciplinary research and innovation need special attention by funding agencies. Successful interdisciplinary projects start with ground-breaking ideas and excellent research proposals, but it is equally important that funding agencies and policymakers take an active role when defining the right framework conditions and support structures for interdisciplinary research.[5]

[4] Evaluation is further examined in Section 1.2. and Section 1.5. on impact assessment.

[5] Stokols et al. (2008), Lyall et al. (2013), and Vienni et al. (2020) suggest that funding agencies acquire more specialist knowledge about the science of team science "to promote organisational learning by providing transferable lessons of relevance to future interdisciplinary programmes along with practical guidance to funders and leaders of such initiatives" (Lyall et al. 2013, 63). For example, this approach has been taken by the US National Science Foundation that for several years has run a programme on the "Science of Science" within the Division of Social and Economic Sciences.

1.2. Evaluation of interdisciplinary research

Funding agencies and research councils rely on different methodologies to evaluate the potential of proposed research as well as its outcomes. Evaluations are used in a variety of contexts comprising peer review; resource allocation; formulation of research policies; interim and final assessments of funding programmes; assessment of organizational, departmental, and individual performance; and allocation of grants from research councils and funding agencies. In the included literature, we find that several different evaluation techniques are employed throughout the science funding ecosystem ranging from qualitative to quantitative methodologies.

In this section, we focus on tools adopted to evaluate interdisciplinary research proposals (*ex ante*) whereas section 1.5. is dedicated to post-grant evaluation and impact assessment (*ex post*). A major challenge for interdisciplinary peer review is how different epistemic viewpoints are to be weighed and which criteria assessment panels should use. Related to these challenges are the questions of who should be involved in the evaluation and how evaluation should be organised (Huutoniemi 2010)? Should external stakeholders be invited to weigh in or should evaluations be made solely on the basis of scientific excellence?

According to Holbrook (2010), peer review serves to assess scientific excellence within academic specialities. It is a process by which a group of individuals renders judgment on the work of others to determine whether that work is worthy of consideration (e.g., for publication or tenure) or support (e.g., grants or fellowships). “Typically, the individuals asked to render such judgements are selected from a pool of reviewers who are considered to be peers of whoever has produced the work to be judged” (Holbrook 2010, 321). The justification for using peer review as an evaluation method is straight-forward: “No one is in a better position to assess the merit of work in a particular area than experts in that particular area” (p. 321). For these reasons, peer review has a built-in bias towards disciplinary science which is the basis of identifying peers and authorising scientific expertise.

Indeed, the link between scientific excellence and disciplinary expertise is so common that interdisciplinarity has become a major challenge for funding agencies (Huutoniemi 2010, König & Gorman 2019). This has led to criticisms that many research and innovation agencies are biased against diversity. Empirical results suggests that diverse teams are less likely to be successful in grant evaluations – even though they are generally more likely to create impact ex post.

Banal-Estañol et al. (2019) estimate that diverse teams are perceived as being less “safe” or less “doable” compared to more homogeneous projects, and that they are more difficult to evaluate because evaluation needs to draw on multiple perspectives (p. 1823). Diverse teams may also be perceived as being more likely to fail for other reasons. Diversity may raise concerns about management and collaboration due to higher coordination and communication costs. Establishing relationships, developing a shared methodological framework and creating a joint problem space across disciplines require substantial resources (Bromham et al. 2016, Boone et al. 2020, Agrawal et al. 2020).

Interdisciplinary proposals are disadvantaged if evaluators apply only familiar criteria of scientific excellence when evaluating projects that integrate various disciplinary contributions, not least because evaluation processes often place significant weight on “the weakest link” (Banal-Estañol et al. 2019, 1827). This observation also relates to the inclusion of knowledge brokers and interactional experts, mentioned by Bammer et al. (2020). In addition to traditional academic expertise and track-record, interdisciplinary teams often require experts in knowledge integration, facilitation and implementation that represent an emergent form of expertise beyond disciplinary excellence. Judging such components require peer reviewers to depart from strictly monodisciplinary criteria and include organisational, leadership, and communication skills in the assessment. Similar issues are discussed by Stokols et al.

(2008) who point out that "the quality of scientific work may be defined differently in the context of interdisciplinary team initiatives than in disciplinary projects" (p. 80).

Several contributions point out that it is not sufficiently clear what constitutes interdisciplinary success or excellence. Is interdisciplinary success measured in terms of breakthroughs and advancements of science? Or is interdisciplinary success measured in terms of integrative approaches and techniques that emerge from the collaborative process? These questions reflect the challenge that interdisciplinary research does not have its own epistemology and that it is characterized by more uncertainties in research processes and outcomes than monodisciplinary research (Ding et al. 2020, 2).

Bromham et al. (2016) encourage funding agencies and universities to experiment with peer review and to conduct research on research evaluation to inform future evaluation practices. There is a clear need to test the widely held belief that interdisciplinary proposals have poorer chances in competitive funding: confirmation could prompt examination of evaluation strategies for interdisciplinary projects while rejection of this claim might encourage more interdisciplinary proposals.

Given that interdisciplinary research is often oriented towards solutions to societal problems, Blythe & Cvitanovic (2021) recommend that evaluation to a larger extent should be based on estimates of real-world impact (a practice manifested, among others, by the European Commission's funding programmes). This proposal resonates with suggestions made by Stokols et al. (2008) to include non-academic stakeholders (such as health practitioners or industrial representatives) as extended peer reviewers to assess research proposals that work to provide scalable solutions.

Other contributions recommend altering evaluation and assessment criteria in academia to better incentivise interdisciplinary research. For instance, Deutsch et al. (2021) point out that outputs aimed at policymakers, practitioners, or other stakeholders should be valued and recognized alongside traditional academic outputs when evaluating research proposals, teams, and programmes, particularly regarding funding decisions (p. 36).

In the context of team science initiatives, Stokols et al. (2008) argue that the quality and scope of interdisciplinary results and outputs (including the development of integrative approaches, the development of training programmes, the emergence of new hybrid fields) should figure centrally in the evaluation of collaborative science. Indeed, establishing flexible, dynamic evaluation and monitoring frameworks from early phases of programs may also make the management of cross-disciplinary programmes more efficient (Boone et al. 2020, 1727).

1.3. Assessing the diversity of research teams

As we observed previously, a central part of evaluating interdisciplinary research has to do with understanding the "added value" or "emergent" properties of collaborative processes. Interdisciplinary excellence is that which lies beyond the contribution of any individual discipline, and which is associated with the integration or synergy of the interdisciplinary team. In this section we turn to the question of diversity in team science, and how funding agencies, according to the literature, can assess diversity of disciplines, skills, and demographics. For example, prominent questions in the literature are whether diversity contributes to innovation, and how to consider diversity in evaluation of grant proposals.

Several contributions point out that diversity is a crucial condition for innovation (Banal-Estañol et al. 2019), and that fostering greater diversity may contribute to building excellence and frontier research (DFG 2016). Diversity is seen both as a normative value and as part of the societal responsibility of academic institutions (EUA 2019). In this context, it is relevant to distinguish between different types of diversity. Importantly, most diversity research has focused on separating *demographic diversity* (e.g., gender, age, race, etc.) from *functional diversity* (e.g., educational background, know-how, information, skills, career trajectories) (Banal-Estañol et al. 2019, Prager 2021). Functional diversity is closely related to interdisciplinarity and may, for instance, be used to assess "team diversity" (in terms of disciplines and approaches involved) as well as "intrapersonal diversity" (in terms of roles, skills, and competences).

According to Banal-Estañol et al. (2019), in a comprehensive study comparing ex ante grant decisions to ex post performance (in engineering and physical sciences), functionally diverse teams appear to be less likely to receive funding compared to homogeneous teams. At the same time, the study indicates, that functionally diverse teams are more likely to produce high-impact results than non-diverse teams (see also Section 2.4). This is a notable finding: while functionally diverse teams are more likely to succeed in producing high-impact research, they are less likely to obtain funding (see also Section 1.2).

Other studies document advantages of demographic diversity, especially that gender diversity leads to more successful outcomes. For example, Hall et al. (2018) refer to a study that finds that mixed-gender teams receive more citations, and that grant proposals that include at least one female collaborator are more likely to be funded (p. 536). The study calls for caution when interpretating these results. According to the authors, the literature on gender in science is severely constrained by the fact that many research teams include only few women. This presents challenges for the interpretation of gender impact on collaboration patterns and outcomes (Hall et al. 2018, 537).

Bloch et al. (2013) investigates motivations for enhancing gender balance. According to their study, researchers generally assume that diversity is important for grant evaluation and funding decisions. They find that female postdocs often are recruited as part of grant application processes, whereas male postdocs are recruited as part of institutional hiring and promotions, indicating that female postdocs are recruited for strategic reasons and have unequal access to tenure-track positions.

Regarding assessment of the cultural, ethnic, and intergenerational diversity of research teams, there is consensus in the literature that this topic is not sufficiently covered by existing research. Mapping social and cultural diversity onto scientific performance and creating indicators that effectively assess different forms of diversity is a highly complex challenge that needs further attention. Generally, there is agreement that a balanced composition of research teams is critical for success, but also that the composition of scientific teams is entangled in cognitive, epistemic, social, and ethical values that cannot be adequately represented by any single indicator or performance metric (e.g., citations).

Some parts of the literature suggest that too much diversity in a team may lead to fragmentation, which in turn may undermine scientific performance. Some analyses have found that collaborations display a

bell-shaped curve with moderate levels of cultural diversity producing higher impact publications compared to low or no cultural diversity (as well as very high diversity). Hall et al. (2018) concludes that large teams with high levels of cultural diversity have a greater likelihood of producing internal conflicts than smaller teams with less diversity (p. 536). Other studies conclude that there is a curvi-linear relationship between team homogeneity and team functionality, i.e., that both highly homogenous and highly heterogeneous teams outperform teams with moderate levels of cultural heterogeneity (DeCusatis 2008, Bozeman & Boardman 2014, Reynolds & Lewis 2017).

Freeman & Huang (2015) find that authors of similar ethnicity co-publish more frequently. However, the study also finds that demographic homogeneity of authors is associated with publication in lower-impact journals and garner fewer citations. On the other hand, diverse research teams more often publish in higher impact journals and receive more citations. These findings suggest that, at least by bibliometric measures, demographic diversity leads to greater contributions to science.

In conclusion, there are several indications that demographic as well as functional diversity does indeed contribute significantly to research and innovation. Diversity is clearly supported by institutional strategies and leadership programmes. Yet, at the level of funding initiatives there is evidence that more diverse groups struggle more to attract funding compared to more homogenous groups. Yet, the same evidence suggest that heterogeneous groups indeed have higher academic impact than non-diverse groups, constituting a paradox of interdisciplinary research.

1.4. Time scales of interdisciplinary research

The complexity and scale of the challenges faced by interdisciplinary teams require working and planning at time scales longer than the usual life cycle of individual research projects (3-5 years). Building coherent integrative environments requires long-term interdisciplinary capacity-building, including interdisciplinary training programmes, seminars, networks, publications, and rewards. Interdisciplinary researchers must see genuine prospects for career progression and feel confident that there will be continuity of funding for interdisciplinarity beyond the scope of individual projects (Lyall et al. 2013, 69).

Results from a survey reported by Vienni et al. (2020) found that successfully funded interdisciplinary projects frequently took a significant amount of time to develop (two years of developing research proposals was not uncommon). During this time, the team was finding partners and developing a common research agenda before applying for programme funding. Similarly, Deutsch et al. (2021) argue that the problem of "time pressure" in research is aggravated in interdisciplinary endeavours as "heterogenous inputs" need to be integrated (p. 34). Integration and team science require programme members to commit substantial time to this inherently iterative process. Deutsch et al. also notice that interdisciplinary research practices are confined by the current incentive structure of academia, which values "disciplinary publications in short time". Interdisciplinary collaborations, in turn, "require long-term time investments and produce a broader range of outputs but fewer academic publications per unit of time" (p. 36).

Drawing on similar observations, Blythe & Cvitanovic (2021) make an argument in favour of long-term funding to support interdisciplinary research. Funding plays a pivotal role in enabling academics to establish new interdisciplinary research fields, supporting a range of research items and activities, including field and laboratory costs, PhD students and postdoctoral researchers, training, and partnerships (p. 9). Funding agencies and universities, according to this argument, should commit to provide long-term support for the broader eco-system in which interdisciplinary teams operate.

Ding et al. (2020) estimates that it "may take years… to become acquainted with and develop respect for each other's disciplinary culture" (p. 8). Mutual learning allows researchers to develop respect for colleagues' expertise in various disciplines. Facilitating this includes assessing team members' background to become familiar with the strengths of the team and motivating team members to teach one another about their respective disciplines, but this takes substantial time and cannot be expected to emerge through short-term contract funding.

> When funders provide long-term funding with a flexible management style, it is possible for cross-disciplinary research teams and programmes to spend time defining shared research problems, and to have time to develop working relationships and trust (Ding et al. 2020, 10)

Hall et al. (2018) articulate the same reasoning when they observe that "in stable, long-term teams, emergent states (e.g., trust and transactive memory) may facilitate high productivity" (p. 541). They also notice some side-effects to long-term funding e.g., that long-term support for interdisciplinary teams may negatively impact new ideas to emerge "because of a lack of newcomers to the team" (p. 541). In effect, they argue that "a team's degree of innovativeness" is determined by stable funding combined with incentives to renew research agendas and include new members. Building effective teams take time: time to get to know each other, both personally and professionally; time to appreciate the strengths that each team member brings to the problem; time to develop a common language that can help overcome each field's jargon (Hart 2018, 31).

1.5. Impact assessment and pathways to implementation

In this final section of Part One, we explore what types of outcomes, effects and impacts funding agencies and governments can expect from interdisciplinary programmes. In a certain sense, the impact of interdisciplinary research is no different from the impact of research in general. Research, innovation, and education translate into real-world applications and added value in numerous ways, driven by commercialisation, collaboration, implementation, and mobility at different scales and in different contexts (NAS 2005b, Stokols et al. 2008, Huutoniemi 2010, König & Gorman 2018, Bozeman & Boardman 2013, Hart & Silka 2020, Deutsch et al. 2021).

In Section 1.2, we covered how appropriate evaluation is critical not only to assess the outputs of interdisciplinary research but also to promote organizational change needed to support interdisciplinary collaboration in terms of rewards, incentives, and career structures. The same is true of impact assessment and implementation pathways. Funding organizations and academic institutions need effective ways to evaluate the outcomes and impacts of their investments in interdisciplinary research and innovation, just as they do for disciplines, to determine whether their goals are being achieved.

However, useful outcomes of interdisciplinary research cannot be measured directly on, e.g., the economy or society, since research outcomes are distributed along a wide spectrum of interactions and embedded in collaborations and organizational learning. A challenge, therefore, is for funding agencies to establish indicators and analytics that can track pathways to impact, in particular, the *academic* impact (or influence) of interdisciplinary research and the *societal* impact of research.

> The diversity of goals encompassed by team science initiatives requires the use of multiple quantitative and qualitative methods to measure their intended processes and outcomes as well as to document their unintended ones (Stokols et al. 2008, 82).

Deutsch et al. 2021 propose that funding agencies and interdisciplinary research programmes adopt a 'theory of change', which is an analytical framework to define expectations, values, and drivers of impact within and beyond academic institutions (p. 33). By using a Theory of Change it is possible to align the mission of the programme with desired outcomes and impacts, rather than assessing the impact of research by universal indicators (e.g., intellectual property, such as patents, licenses, royalties, spin-offs, etc.). For instance, mission-driven research and innovation may strive to maximize the impact on public policy rather than on the business sector, and therefore needs appropriate measures to trace and evidence interactions with policymakers.

Within the human and social sciences, collaboration with the cultural sector (e.g., museums, archives, libraries, media) may be the main pathway to impact, which largely fall outside established bibliometric and econometric indicators and assessment frameworks. A Theory of Change begins with the premise that individual programmes and projects should develop unique mechanisms for knowledge translation and knowledge exchange, and by the same token establish appropriate indicators to capture such activities and their outcomes (Deutsch et al. 2021, 33, 37).

Deutsch et al. (2021), NAS (2005b), and Ding et al. (2020) propose to assess the impact of interdisciplinary programmes by taking into consideration the inherent complexity of the problems they are trying to address (or the technologies they are trying to deliver). By considering the complexity of societal challenges and generative technologies, it becomes more important to assess the *contribution* of interdisciplinary teams to problem-solving, capacity-building, and technological platforms than to establish direct links (*attribution*) to specific outcomes. Only very rarely is a successful product or process the unilateral consequence of individual research and innovation projects. Instead, impact

assessment should focus on the contribution of interdisciplinary research and innovation teams to create capacity within the wider innovation eco-system in which products and processes are developed.

For most challenge- and mission-driven funding initiatives the goal is to support transformative science and innovation that contribute to specific societal solutions in the medium- and long-term. For instance, interdisciplinary funding instruments that are driven by a mission or challenge will often include collaboration and partnerships with different stakeholders, and therefore include impact pathways from the beginning. For curiosity-driven, blue-sky interdisciplinary science stakeholders and partnerships may not be included from the beginning of the research process. Rather, academic and societal impact may arise directly or indirectly from interdisciplinary breakthroughs by contributing to new industries, technologies, and organisational learning in the long-term.

US National Academies (2005b) argue that successful interdisciplinary programmes have impact on "multiple fields or disciplines and produce results that feed back into and enhance disciplinary research" (p. 150). Interdisciplinarity also creates researchers and students with expanded research capacities in more than one discipline and with an enhanced understanding of the interconnectedness inherent in complex problems. According to NAS (2005b), standard metrics for evaluating disciplinary research can also be applied to interdisciplinary science if handled with precaution: the use of metrics, such as publications, citations, co-authorships, and successful grant proposals; benchmarking with other programmes (when comparable programmes exist); and national or international awards for and recognition of researchers. However, the NAS report states that interdisciplinary research needs additional measures to capture the integrative efforts that are crucial for developing new techniques, theories, and applications.

> Evaluating interdisciplinary productivity can be complicated because, although in some situations interdisciplinary research may take more time than disciplinary research, it may have a high degree of depth and importance of achievement. The contribution achieved by a research team may be more than the sum of the individual accomplishments (NAS 2005b, 153).

Sometimes, interdisciplinary programmes are so large that they generate impact in multiple fields and industries. Examples are the Human Genome Project, the Manhattan Project, the theory of plate tectonics, climate modelling or the development of fibre optics. A current example is the development of COVID-19 vaccines that draws upon expertise from several fields of microbiology, immunology, virology, engineering etc. as well as psychology, economics, communication etc. Assessing the interdisciplinary impact of such research and innovation programmes cannot merely rely on standard citation metrics but needs to include assessment of integration, context and implementation using a mix of quantitative and qualitative measures (DeCusatis 2008, 158).

To assess the impact of interdisciplinary innovation, the Evaluation of Innovation Fund Denmark (DMHES 2019) recommends that more comprehensive data should be collected about the different activities of the foundation and its impact in the Danish research and innovation ecosystem.

> IFD should become rich in quality curated data about the outputs, outcomes and impacts of the programmes it has funded, share this data widely and open them to independent research analysis and international comparison (DMHES 2019, 9).

For this to happen, the funding agency should adopt new key performance indicators for the success of interdisciplinary research and innovation that are measurable, e.g., impact of funding on company growth, new innovative products, patents, collaborations, funding of public research and development etc. (DMHES 2019, 36).

Knowledge brokers

Several contributions in the literature highlight the importance of including impact and implementation skills in the composition of interdisciplinary teams.

Gordon et al. (2019) point out that translational competencies are needed in interdisciplinary research organizations to more effectively accelerate the impact of research. Because of the nature and scale of societal challenges and missions, it is part of the mission leadership to oversee partnerships and impact management (p. 648).

Hall et al. (2018) make the same point by arguing that large-scale interdisciplinary consortia need to include "knowledge brokers" that are able to "connect otherwise isolated individuals and help to diffuse innovative ideas within a network" (p. 537). Knowledge brokers may be "publishing with a variety of different scholars" and facilitating the involvement and co-creation of stakeholders and research collaborators, which, in turn, is associated with higher research impact (p. 538). Furthermore, Hall et al. (2018) find that "connections among researchers can introduce greater diversity of perspectives, either directly (via co-authors) or indirectly (through network connections), which can enhance research outcomes" (p. 540). However, the study concludes that "further research is needed to understand [how] connectivity across researchers can increase research impact" (p. 540).

At the leadership level, Hart & Silka (2021) argue for the importance of the motivation to "make a difference" and contribute to something "larger than research" and to "link knowledge with action". This aspiration is "an indispensable, renewable resource for navigating uncharted waters and improvising our way to solutions." (p. 1). Linking knowledge with action can be achieved by including "societal actors" in the research design and by building partnerships with stakeholders spanning all levels of government, communities, the private sector, non-governmental organizations (NGOs), and civil society. For funding agencies and universities this approach implies aspirations to motivate researchers "to develop a shared culture that aligns with their passion to create a better world." Building an "impact culture" should figure as a "core value" that helps promote collaboration and coordination (p. 2).

Bammer (2020) encourages funding agencies and universities to take a proactive role in supporting implementation specialists, knowledge brokers, and experts in research integration. This type of expertise is often neglected but is instrumental for interdisciplinary teams to have societal impact.

> Addressing complex societal and environmental problems requires specific expertise over and above that contributed by existing disciplines, but there is little formal recognition of what that expertise is or reward for contributing it to a research team's efforts. In brief, such expertise includes the ability to identify relevant disciplinary and stakeholder inputs, effectively integrate them for a more comprehensive understanding of the problem, and support more effective actions to ameliorate the problem (Bammer 2020).

Integrative expertise (or meta-expertise), according to Bammer (2020), is a form of interactional expertise, i.e., "the ability to understand disciplines, professional practice and community experience without being trained in those disciplines or professions". Tackling complex societal problems and delivering tangible impacts calls for interactional experts to draw out relevant interconnections as well as to help set effective boundaries around the problem. Interactional experts and knowledge brokers are required in interdisciplinary programmes to appreciate the cultural, political, and economic circumstances that constrain how real-world problem are framed and tackled.

PART TWO

Part Two addresses the multiple ways in which interdisciplinary research is organised, managed, and creates knowledge, innovation, and breakthroughs (inside-out). This part is mostly based on academic literature as well as contributions published for general academic audiences. The published research on research organisation, implementation, and management is comprehensive, and contains hundreds of contributions. In this part, we focus on contributions that address principles of team science, academic leadership, academic workplace cultures, and team composition.

By focusing on team science and team composition, the review discloses a number of principles governing successful interdisciplinary teams. Furthermore, this part examines key characteristics of team composition and the influence of team diversity on team performance, including attitudes towards diversity and strategies to foster inclusive leadership programmes. We also examine factors related to the formation of research teams, including the physical proximity of team members, the level of social trust, and evidence-based practices to accelerate joint problem solving.

To structure the presentation, we have identified five major themes in the literature, which cover issues relevant for examining the following topics:

1. Principles of team science and team construction
2. Academic leadership and collaborative competences
3. Psychological safety and work environment
4. Diversity and inclusion
5. Recruitment, onboarding and mentoring

2.1. Principles of team science and team construction

Principles for successfully leading and supporting interdisciplinary teams vary significantly across programmes and projects. What works well in one context may not work in another. As we examine in this section, team science and team construction are influenced by a variety of factors, including the disciplines involved, the choice of scientific questions, and contextual factors.

To understand how team science can be managed effectively, it is necessary to examine both drivers and barriers to conducting team science. For members and leaders of team science, it is critical to know how to coordinate and integrate disciplinary approaches and develop strategies to improve team-work and problem-solving. The literature on these topics is extensive, ranging from management studies, organizational theory, social psychology, cognitive science, and anthropology. For this reason, our review cannot provide a simple answer to the question "what constitute effective team science"? Rather, successful teams are the result of several interacting and multi-level factors that influence the effectiveness and dynamics of teams – including funding, organisational factors, and personal skills (DeCusatis 2008).

In this section, we aim to establish some core principles of team science and team construction. Our starting point is that successful interdisciplinary teams are founded on excellent disciplinary experts as well as interactional experts, as pointed out by Bammer (2020). Interactional experts are experts in interaction and integration, whether it is between scholars from different disciplines or between researchers and stakeholders. The key to success of interdisciplinary teams is that their construction and leadership reflect the competences needed for "research integration and implementation to effectively harness the contributions of the full team" (Bammer 2020, 2). A founding principle of successful teams, therefore, is the ability of the team leader to understand disciplines, professional practices, and practical problems without being trained in those disciplines him- or herself. Knowing the key characteristic of the research problem in question and at the same time knowing how to structure a group of team members around it, is key to the success of interdisciplinary teams (Stokols et al. 2008).

Bozeman and Boardman (2014) argue that successful teams require regular team meetings, face-to-face proximity, online coordination (especially in the absence of face-to-face proximity), shared values (e.g., emphasizing collaboration, mutual understanding and knowledge sharing across disciplines), trust and interpersonal skills, and planning (p. 29).

Vienni et al. (2020) state that a core principle of team science is associated with overcoming the assumptions, values, and worldviews embedded in different disciplinary cultures and embodied by individuals and organizations. "Learning to navigate relationships within a collaboration", according to Vienni et al. (2020), is a crucial and defining part of team science (p. 6).

Hart (2018) maintains that "the art of collaboration" is just as important as scientific excellence when managing scientific teams. A defining feature of successful collaboration is the ability to combine efforts, building relationships, promoting shared values and goals, and establishing personal relations and networks (reinforced by team building exercises such as meetings, seminars, and retreats). Team science, according to Hart (2018), should be driven by the attempt "to create an organizational culture that is founded on, and advanced by, a shared commitment to open communication, mutual respect, and trust" (p. 31).

Hall et al. (2018) encourage researchers and research organizations to consider the full range of factors influencing interdisciplinary teams: successful team science needs to be supported by appropriate science policy instruments and should at the same time be grounded in a psychologically safe

environment that "aims to synthesize and build upon methods, concepts, and theories from a range of relevant disciplines and fields" (p. 533). [6]

A key feature of team science is the principle of "integration". Integration is mainly understood in terms of integrating research activities, creating a stronger collective understanding in the team, and synthesising methods, concepts, and theories from different fields (Hall et al. 2018, Lyall et al. 2013, Bammer 2020, Boone et al. 2020). Since no individual has all the qualities needed for solving a complex problem, it is important to build a team that integrates different capacities.

> Scientific integration […] moves from disciplinary focus, through inclusions of multiple disciplines in a study, to the *integration* of those multiple disciplines in question-asking, methodology, conclusions and application (Boone et al. 2020, 1724).

Integration may also be understood beyond scientific integration to include linkages with societal, business, and policy institutions. For example, mission-oriented science and innovation requires the integration of multiple forms of knowledge and expertise of end-users. This form of integration involves that participants and stakeholders (communities, decision-makers, companies) are involved in posing research questions, co-producing knowledge, and assessing outcomes (Boone et al. 2020, 1725).

Additionally, integration involves developing a coherent and consistent long-term research strategy, i.e., "aligning upcoming research proposals and catalysing new integrated research projects" with the aim of building capacity for scientific and social problem-solving (Deutsch et al. 2021, 30). Integration is not about reaching scientific consensus among team member but rather about creating "a common ground that would recognize and value difference in perspectives instead of assimilating them" (p. 34). At the same time, integrating perspectives from various disciplines into a comprehensive whole constitutes a "substantial cognitive challenge" and critical role for academic leaders (p. 37).

Team construction

In a certain sense, the principles of team science elaborated above already point to several implications for team construction. Team members should be recruited as part of an ambition to build an integrated team driven by shared objectives and problem-solving. However, according to Agrawal et al. (2020), "there is a tendency to want to partner with everyone who is interested, particularly where the challenges are complex, and the sense of urgency is strong" (p. 2). This may lead to a suboptimal situation in which team members pursue different goals and the common purpose is lost. Instead, the authors suggest, team leaders should develop "clear processes for assessing whether and with whom to partner" and how to measure the success of partnerships (Agrawal et al. 2020, 2).

Before composing a team, it is important to ask key questions: Are the values and objectives of the team members aligned with the research strategy? Is there enthusiasm from individual members to establish and commit to a clear governance structure? Is the proposed research problem intellectually stimulating and impactful? According to Boone et al. (2020), it is only when the members can answer these questions affirmingly that team leaders should invest resources to build trust and motivation (p. 1726).

Following Deutsch et al. (2021), attention to team composition is particularly important when forming new research groups by bringing together team members who have not previously collaborated. In this situation, it is important to consider the breadth of disciplines, the diversity of expertise and to challenge "hierarchical positions" involved in groups, especially among junior and senior members (p. 35). In the

[6] We explore principles of trust and psychological safety further in Section 2.3.

process of forming a team it is helpful to "bring out implicit assumptions", which are critical for the project leader and group members to interrogate to collaborate effectively.

For well-established teams with a track record of close collaboration, it can be difficult to challenge each other and discuss underlying assumptions. Teams have a tendency, in the words of Deutsch et al. (2021), to develop higher levels of "homogeneity" over time where group members reaffirm hierarchical positions based on prior collaborations. However, to sustain diversity and agility and to combine disciplines to form integrative approaches it continues to be challenge to "break out of the usual way of reasoning" (p. 35).

Ding et al. (2020) also emphasize the role of shared values when forming teams. "Individual qualities such as open-mindedness to other disciplines and learning are valued in the selection of cross-disciplinary team members" (p. 4). Research partner selection in many cases is based on pre-existing networks, supplemented by informal contacts. Prior established working relationships can facilitate cross-disciplinary collaborative research, by enabling trust and problem-solving that draws upon pre-existing knowledge and workflow (p. 7). Identifying and attracting new partners and establishing a collaborative mindset can be challenging.

> Team leaders should bring potential research collaborators together early to agree on research problems. Reading and discussing key articles together is helpful and they should not be afraid to disengage from partners that cannot find ways to work together productively, or who do not meet expectations managed through planning for respectful exits (Ding et al. 2020, 6).

Clearly defined roles, goals, and values from the onset ensure that team members understand what is expected of them and how everyone contributes to the team. A diverse team of experienced and early-career researchers, according to Ding et al. (2020), is the most effective for facilitating interdisciplinary research. Experienced researchers provide guidance and support, and early-career investigators implement research projects and are supported to publish findings. For this to happen, team leaders should instil a sense of "being more collaborative than competitive" (p. 6).

Hall et al. (2018) look at the productivity of scientific teams in order to determine an optimal size and composition. The available evidence suggests a positive correlation between team science and publication outcomes within certain thresholds. Some evidence indicates that "larger teams often are more productive and impactful" but also that larger teams may be vulnerable to conflicts and fragmentation (p. 536). Team size has also been found to be associated with other types of outcomes, for instance, studies have found that smaller teams are more likely to generate new disruptive ideas whereas larger teams are more likely to further expand breakthroughs in new directions (p. 536).

Although some research suggests there is an ideal team size of six to nine participants (measured against publication outcomes), findings from the literature indicate that ideal team size differs based on various influencing factors, including the disciplines involved, the scientific questions being explored, and contextual factors. For instance, "some research shows that when the number of institutions involved in a science team within a project increases while the number of authors, countries, or departments does not, citations and readership are reduced" (Hall et al. 2018, 536). The key to successful team, according to Hall et al. (2018) is that team members align their goals (p. 541). This highlights the need for time, tools, and resources to facilitate joint problem-solving and establish a shared understanding and purpose.[7]

[7] Team diversity is examined in more detail in Section 1.2. Recruitment and on-boarding are examined in Section 2.5.

2.2. Academic leadership and collaborative competences

It is important to define not only the distinguishing features of effective scientific collaboration but also the essential facets of successful team leadership. Leadership is required to inspire diverse individuals to align their motivations with a common goal while simultaneously managing expectations to match feasible interdisciplinary outcomes (Lyall et al. 2013, 66). Determining the kinds of expertise that are needed to solve a complex problem is itself a key leadership problem. Knowing how to lead diverse team members towards a collective goal is a critical component of interdisciplinary research and innovation.

Agrawal et al. (2020) propose that leaders of interdisciplinary research organizations are selected using the same qualities and skills that make any leader successful: creativity, humility, open-mindedness, long-term vision, and being a team player. In addition, Agrawal et al. (2020) identifies eight leadership principles that are specific to interdisciplinary projects. Leaders need to cultivate: (1) vision beyond the status quo (2) collaborative leadership, (3) partnerships, (4) shared culture, (5) communications with multiple audiences, (6) appropriate monitoring and evaluation, (7) perseverance, and (8) resources for success (p. 1-2). Managing the resources for successful interdisciplinary research projects entails:

- **intellectual resources**, recognizing and engaging academic expertise from a variety of disciplinary sources
- **institutional resources**, supporting collaborative behavior, stimulating non-traditional outputs and outcomes, engaging practitioners, celebrating interdisciplinary work, and promoting career progression.
- **financial resources**, developing nimble ways to leverage limited soft-money budgets and experimenting with seed funding for interaction and collaboration.
- **physical resources**, recognizing that co-location of researchers from different disciplines sparks serendipity, that co-location with external stakeholders can facilitate co-production and co-creation of solutions, and creating access to critical infrastructure and technology (p. 5).

Boone et al. (2020) make similar suggestions in their study of interdisciplinary leadership within sustainability science. They argue that interdisciplinary leaders often must be more persuasive than other team leaders "to convince researchers to follow the unsettled and novel pathways of interdisciplinary research" (p. 1725). To succeed, leaders of interdisciplinary projects "must promote a new scientific culture that values and promotes interdisciplinary research and activities" (p. 1726). In particular, Boone et al. (2020) emphasize that leaders should guide their projects by "articulating and establishing new norms, finding ways to reward appropriate collaborative behaviors, and discouraging lapses into cultural norms of a narrow disciplinary past" (p. 1726).

Lyall et al. (2013) present key practical and organisational steps that large-scale interdisciplinary research initiatives should take to promote and support collaborative problem-solving and integration. Among these steps are leadership.

> Pro-active management is crucial throughout an interdisciplinary initiative in order to achieve genuine interdisciplinary integration. Focusing on network- and community-building in the early stages of a research initiative contributes greatly to the degree and extent of integration and thus, the synergy achieved. This adds value to the research investment and develops long-term capacity for interdisciplinary research (Lyall et al. 2013, 67).

In the same study, the authors reflect upon the fact that management skills are not routinely taught to academics, and that the work that goes into promoting synergy and integration in a research project is "often overlooked or assumed to emerge spontaneously" (p. 67). It is therefore important, according to Lyall et al. (2013), to recognize the demands posed by the process of achieving genuine interdisciplinary

integration, and to identify responsibilities for various aspects of active management so that this is developed and maintained throughout the lifecycle of the grant or project (p. 67).

Gordon et al. (2019), also departing from the field of sustainability science, call for specific efforts to develop future leaders of interdisciplinary organisations, and propose concrete steps for academia, governments, and funding agencies to foster such leadership (p. 647). Among those efforts are special attention to developing the skills, experience, and aptitudes of team leaders "to provide an environment where interdisciplinary science flourish." (p. 647). The authors describe the key features of interdisciplinary leadership as follows (selected):

- **Nurture partnerships and interactions**. Building a comprehensive knowledge base by using a 'spider web' rather than 'tree' model of knowledge.
- **Harmonize values and empirical rigour**. Leaders need to install a sense of purpose, a logic model or theory of change for guiding their strategy.
- **Promote respect for multiple ways of knowing**. Drawing on diverse forms of knowledge and know-how increases the likelihood that science will deliver solutions that address real-world challenges.
- **Foster equity, shared leadership, and consensus**. Interdisciplinary leaders need to take into consideration equity issues, and their consequences for power structures, within and outside the organization. This leads to greater transparency and shared leadership, to engage diverse disciplines and points of view, and ensure decision-making by consensus
- **Cultivate flexibility**. Research takes time, and even more so when it requires stakeholder involvement and co-production. Often, research time frames do not fit easily with the urgency of decision-making for policy and practice.
- **Be resilient in the face of pressures**. Dealing with real-world issues often involves challenging established power structures, ways of operating and vested interests both within and outside research organizations (p. 647-48).

A similar point is made by Hart et al. (2018) who in their research on team leadership found "that team members were more satisfied with collaborations and made more progress towards project goals when they used shared decision-making processes that included opportunities for multiple viewpoints to be shared and time to find common ground" (p. 31).

Ding et al. (2020) emphasise that team leadership should identify and minimize academic hierarchies by **empowering** every team member to participate on an equal footing, and "developing an understanding of the contribution of other disciplines" (p. 7). According to this study, team leaders should have "knowledge integration" as an explicit goal: they should respect disciplinary differences and at the same time facilitate mutual discussions and manage expectations by identifying the limitations of the involved disciplines (p. 6). Successful team science requires a professional leader with personal compatibility, mutual respect, and trust.

> Trust is built by leaders who maintain fairness in the recognition and reward of team members' contributions. Therefore, leaders' personal qualities, including trustworthiness, transparency, and openness to different approaches and perspectives, have been shown to encourage and influence team members (Ding et al. 2020, 6).

Among the leadership skills mentioned by Ding et al. (2020) is also strong internal and external communication. Successful team leaders communicate their vision effectively and catalyse the integration of disciplines with team-building skills, engaging team members as well as non-academic stakeholders. To harmonise team efforts, it is necessary to have "a clear and shared vision on what a successful cross-disciplinary research project looks like" (p. 6).

Collaborative competences

Nurturing collaborative competences is a core objective for most of the contributions included in this literature review. In a certain sense, every section of this review touch upon collaborative competences; whether it is the competence to compose teams, to effectively manage diversity, to facilitate knowledge integration, or to create a sense of shared values and purpose. However, in this section we are examining some of the key competences and qualities of members participating in collaborative processes.

If we return briefly to Agrawal et al. (2020), introduced in the beginning of this section, most of the qualities and skills that a team leader needs are also needed among members: creativity, humility, open-mindedness and being a team player. Engaging in partnerships, sharing values, interacting, and communicating with stakeholders and experts from other disciplines, and solving joint problems, are essential competences for successful collaborative projects.

Borrowing a metaphor used in normal job recruitment, team members in interdisciplinary research and innovation need T-shaped skills. The vertical bar on the letter *T* represents the depth of related skills and expertise in a single field, whereas the horizontal bar is the ability to collaborate across disciplines with experts in other areas and to apply knowledge in areas of expertise other than one's own. Bammer et al. (2020) argue that team members must combine "contributory expertise" (the ability to make scientific contributions within a special field of expertise) with "interactional expertise" (the ability to build bridges between fields of expertise) "to work effectively and knowledgeably with a team" (p. 2). To effectively harness the contributions of the full team, members will need both contributory and interactional expertise, including expertise in research integration and implementation.

Expertise in integration and implementation is particularly important in research and innovation projects that include stakeholder and non-academic collaborators. In this situation, focus is not only on building a dynamic team but on nurturing partnerships and building a shared understanding of complex problems and potential solutions that can inform practitioners, end-users and decision-makers (Deutsch et al. 2021, 31). Expertise in facilitation and integration, according to Deutsch et al. (2021), further involves personal qualities such as openness, empathy, flexibility, adaptability, and persistence (p. 37).

The same point is made by Addington (2020) who stresses the importance of facilitation skills in team leaders, for instance sharing relevant examples, stories, and analogies to further learning and asking engaging questions to elevate the conversation (p. 58). Affara (2020) makes a similar case when she argues that "facilitation skills can improve leadership of cross-disciplinary projects" and enhance the flexibility of collaborations to contribute towards social learning and social change.

Ding et al. (2020) list as a key collaborative competence individual awareness of the various disciplinary assumptions, concepts, and methods that underline interdisciplinary collaborations. Such awareness can be obtained by attending events and through exposure to diverse communities. The willingness of team members "to explore and learn new ideas, knowledge and perspectives, and to share theirs, coupled with accepting their disciplines' limitations are enabling factors" for successful collaboration (p. 4). The authors also emphasize team member's ability to rapidly digest information and its implications: "Researchers should be mentally prepared for unexpected results, and to allow for critical self-reflection on assumptions of involved disciplines and the decision-making processes" (p. 4).

Finally, Hall et al. (2018) mention that a key feature of team performance "is the development of shared mental models among team members" (p. 538). The ability to coordinate tasks, processes, and scientific mental models are useful to help bridge differences in underlying assumptions to facilitate shared

understanding and problem-solving. For example, key skills such as “knowledge sharing”, “information acquisition”, and “information dissemination” all have “positive effects on team learning, which, in turn, has a positive effect on team performance” (p. 538).

> Successful scientific teams are bolstered by decision-making and communication competencies that enhance mutual understanding and facilitate the inclusion of diverse ideas. Among established teams, frequent face-to-face meetings, whether for team coordination or substantive discussions, supports effective communication and contributes to increased productivity and greater impact (Hall et al. 2018, 539).

Similarly, Boone et al. (2020) suggest that one of the most important competences underlying successful collaborative teams is “a sharing attitude.” This feature may be difficult for those trained in science as an individual, competitive pursuit. Sharing data in clear, well-documented, understandable formats is a key feature of effective interdisciplinary teams (p. 1726).

2.3. Psychological safety and work environment

In this section, we discuss a number of psychological issues, which may arise during collaboration in diverse teams. These include establishing psychological safety and creating a healthy work environment. According to the literature, physical co-location of collaborators is among the most promising means for handling such challenges.

Job market safety is a recurring issue among junior faculty members. There is a disproportionate number of PhDs and postdocs hired in team science initiatives compared to the number of participants with permanent academic positions. At the same time, participation in interdisciplinary teams can be counterproductive to career support since interdisciplinary researchers find it more difficult to get into permanent positions than well-established disciplinary researchers. To handle this issue, larger research initiatives need to incorporate career-development and training, which may provide participants with collaborative and translational skills that are valued in the academic job market – both in universities and outside – e.g., in policymaking and practice (Stokols et al. 2008).

Deutsch et al. (2021) show that in many cases, interdisciplinary collaborations produce a broader range of academic outputs but fewer publications per unit of time. Simultaneously, researchers are faced with demands to produce contributions that are recognisable within their original field of study. This situation creates the potential for double jeopardy for interdisciplinary scholars, because traditional standards of disciplinary excellence have to be combined with interdisciplinary criteria and integrative skills. At the same time, the question of career progression is pivotal for building long-lasting capacity that goes beyond short-term project funding. When considering academic careers, funders need to ensure that interdisciplinary researchers are not automatically considered to be 'second-tier', for example, with respect to career progression (Deutsch et al. 2021; Lyall et al. 2013, 69). It is worth noticing that this issue may have an especially negative effect on attempts to establish gender balance, since lack of job safety, according to several studies, is hypothesized to be especially unappealing to female scholars (DFG 2016). A key driver of establishing psychological safety, therefore, is to establish work safety and predictable career development.

Other aspects of psychological safety require attention as well. A major challenge of any collaborative effort is to create a safe environment for the discussion of controversial scientific issues (Rozovsky 2015). It has been shown that emotions of insecurity are more common in interdisciplinary research, due to unfamiliar processes which may prompt stress, feelings of incompetence and even anxiety. In such cases, a "trusting and supportive cross-disciplinary research community helps overcome emotional difficulties" (Ding et al. 2020, 4). Trust, as discussed previously, provides a critical foundation for having open and honest discussions about the science without the risk of team members interpreting challenges or hard questions as personal attacks (Bennett & Gadlin 2012, 772).

> Creating an environment in which respectful disagreement can occur, productive discussion around difference is fostered, and all the while conflict and negative emotion is contained can lead to enhanced shared learning and focus everyone's efforts on the scientific project at hand (Bennett & Gadlin 2012, 773).

To facilitate fruitful and safe interactions, the literature points to physical place as an important dimension. Placing diverse groups of researchers together, makes inspiration and conversations more likely to emerge (Boone 2020). According to Banal-Estañol et al. (2019), spatial re-location makes team members more likely to produce high-impact papers (p. 1827). Face-to-face interactions are important to create cohesion and knowledge-sharing across team members and units. The literature suggests that working in the same department or institution is a contributing factor when forming new collaborations. Other studies show how academic conferences contributes to the development of collaborations over

time. For those who are located within the same institution, “path overlap” (i.e., overlap in functional and physical space) and social proximity increase the likelihood of successful collaboration (Hall et al. 2018, 537).

Physical infrastructure, including co-location with external stakeholders and partners, can facilitate the co-production of knowledge and solutions (Agrawal et al. 2020, 5). Regular meetings, ranging from informal chats (such as lunch and coffee breaks), brainstorms, networking events, seminars and workshops, sandpits (meetings spread over several days), and off-campus retreats, are drivers of collaborative behaviour since they encourage communication on various aspects of the research and innovation process. Informal interactions raise participants’ comfort levels, especially in the early phase of collaboration, and encourage creativity (Ding et al. 2020, p. 9).

> Meetings are especially useful in times of conflict, ensuring accountability and strengthening working relationships. Off-campus retreats are useful to promote open dialogue and trust, to address cross-disciplinary tensions and to facilitate intellectual integration (Ding et al. 2020, 9).

The literature shows that factors such as the built environment, organisational structures, and the available resources has positive effects on the formation as well as the productivity of collaborative teams (Hall et al. 2018). The design of physical spaces may nurture successful interdisciplinary research by facilitating mutual understanding and trust through informal interactions (Ding et al. 2020, p. 9).

In general, it is recommended to encourage and provide resources for researchers with potential to work across disciplines – especially those who have the capacity to take an integrative role within an interdisciplinary team. Bringing people together physically in a mix of formal and informal settings may be especially important when they are from different traditions and disciplines. There is, thus, a crucial facilitating role for funding agencies and universities in building capacity “if they are to meet the challenges and demands of complex, multi-dimensional problems” (Lyall et al. 2013, 69).

2.4. Managing diversity and inclusion

The last decade has seen an increase in studies that address gender diversity in science and higher education (Munar & Villesèche 2016, Nielsen, Bloch & Schiebinger 2018, Lauring & Villesèche 2019). Studies that examine gender diversity take at least two main approaches: (1) studies of attitudes towards diversity in team science, including leadership issues such as career development, organizational culture, work environment, rewards, and ethics. And (2) studies that examine the effect of diversity on scientific performance and innovation, e.g., bibliometric performance of diverse teams and their level of performance quality (for instance, task completion, achievement of organisational objectives, etc.). Numerous studies have been published in each of these streams of research.[8]

In this section, we examine some of the main findings in the literature on managing diverse teams with a special focus on gender diversity. We do this in two parts. First, we look at the correlation between diversity and team performance, and second, we examine leadership principles for creating equality in science and innovation.

Nielsen, Bloch & Schiebinger (2019) argue that gender diversity matters for the outcomes of scientific research processes, highlighting that diversity in groups matters for their ability to perform well in creative tasks (p. 726). Among other things, the authors point out that team members' beliefs about the possible benefits of gender diversity can matter for team outcomes, citing various prior studies. For example, Lauring & Villesèche (2019) found that openness to diversity is positively associated with performance in gender-diverse teams. Based on survey responses from 1,085 academic team leaders, the study found that the effect of openness to diversity (defined as pro-diversity attitudes in the team) is stronger when team gender composition converges towards numerical balance. These findings show that perceptions and attitudes can be pivotal to whether or not a team benefits from diversity (p. 244).

> "Openness to diversity leads to a number of group-level outcomes. It fosters an environment where individuals value and respect the views of demographically dissimilar team members and actively collaborate with them. They can improve group processes in diverse settings, lead to the development of alternative solutions to problems and also positively impact the group's ability to resist pressures to conform to dominant positions and thereby see new opportunities (Lauring & Villesèche 2019, 245).

The study found that gender diverse teams with pro-diversity beliefs perform better when working with heterogeneous information. Such results might be even stronger in fields where teams are typically exposed to a large variety of perspectives and information, for example in interdisciplinary collaboration (p. 245). The data indicates that pro-diversity attitudes are correlated with general team performance, measured e.g., by the team's ability to get along, solve problems, and achieving organisational objectives (p. 247-48).

Campbell et al. (2013) found that gender-heterogeneous teams typically produced journal articles that are more cited than teams comprised of high-performing individuals of the same gender: peer-reviewed publications by gender-heterogeneous authorship teams received 34 percent more citations than publications produced by gender-uniform authorship teams. This may indicate that research by mixed-gender teams have greater academic impact on scientific discussions.

McKinsey & Company in their study "Bridging the Talent Gap in Denmark" reviews several contributions to the literature that find positive effects of diversity – both endowed (e.g., gender, race) and acquired

[8] For a recent comprehensive literature review of diversity and gender in science and research, see DEA ("Diversity in Science and Science Funding: A Mapping of the Literature", 2021).

(e.g., experience, cultural capital). Building on prior studies they find that diverse teams have "superior team performance on measures such as innovation, collaboration and critical thinking" (IFD 2018, 16). Different problem-solving approaches and complementary skills "serve to promote creativity and debate, ensuring more alternatives are considered and additional rigor is applied when identifying solutions" (p. 16). The study also highlights that diversity in research and innovation ensures that new products and technologies "cater to the needs and interests of both genders" (p. 16). A case in point is the design of inclusive algorithms. Machine intelligence learns from observing the data that it is presented with, and if gender stereotypes permeate this data, the resulting application of the technology may perpetuate and even amplify unconscious bias (IFD 2018, 17). To be able to understand and correct these biases, diversity in research and innovation is paramount.

Inclusive leadership

Given the evidence presented in these and many other studies, university managers and science policymakers should see gender diversity as a key driver of excellence and innovation. Yet, careful management is required to maximize the benefits of diversity for scientific discovery (Nielsen, Bloch & Schiebinger 2019, 726). Studies that examine gender diversity over longer periods clearly indicate that there is a global under-representation of women as knowledge leaders in academia (Munar & Villesèche 2016). Gender patterns in science have been shown to be highly persistent and resistant to change (Munar & Villesèche 2016, 36). In order to change this situation, it is necessary to adopt leadership strategies that actively encourage inclusion and integration of diverse teams.

Building a team is always an exercise in managing differences and embracing diversity. This is especially true in the case of research teams, which bring together individuals from various disciplines and specialties, at different stages in their careers, and often from different institutions (Bennett & Gadlin 2021, 771). Lauring and Villesèche (2019) shows that team integration and shared values are important to harness the benefits of diversity. Team members holding similar values will have more frequent and deeper communication, which helps reduce conflicts and increase efficient use of knowledge, making it an essential leadership challenge to instill equality and inclusiveness in scientific teams (p. 243).

Munar and Villesèche (2016) support a similar strategy when they suggest hierarchical gendered patterns should be replaced by an inclusive academic workplace culture reinforced by a more balanced representation of women as knowledge leaders (p. 36). They also suggest a number of practical actions and recommendations for how to design inclusive leadership programmes. For example, the article suggests that in order for a knowledge institution to become an active change-maker it is important to develop and establish "an inspiring strategic vision on gender, talent and equal opportunities", "encourage a leadership culture of innovation and creativity", and "promote activities such as seminars and workshops that encourage self-reflection and processes to identify possible biases and unfair cultures" (p. 14).

In the process of changing the academic culture, Munar and Villesèche (2016) stress the importance of "developing tools to enhance the visibility of diverse talents and nurture a more holistic view of excellence." They argue that it is necessary to "differentiate between entry-level criteria and top-level performance and excellence criteria for academic positions" and create management tools that focus on collective knowledge production rather than individual performance (p. 19).

> "It is therefore important to not only increase awareness, but actually adopt actions that can result in a positive empowering effect across the leadership" (Munar & Villesèche 2016, 30).

Establishing mentoring schemes, nominating more balanced candidates for honorary doctorates, and potentially establishing a women-only visiting professorship are other strategies suggested to enhance gender diversity in science.

At the European level, several policy documents have emphasized the need to strengthen diversity and inclusiveness in higher education and research, promoting inclusive leadership and common values of non-discrimination. The European University Association points out that "giving priority to diversity, equity, and inclusion in universities is a strategic choice" (EUA 2019, 14). Change should be encouraged both at the local and central level and by institution-wide policies and strategies. In a survey among European academic leaders, the majority of respondents perceived inclusiveness and diversity as "an explicit value for their institution and a part of their social responsibility" (EUA 2019, 14). Measures to overcome barriers and success factors are to a large extent internal to the institution. Commitment by institutional leadership is by far the most important success factor according to EUA (p. 41).

Several studies have argued that gender inequality challenges in academia should be seen as the result of a complex combination of factors – including, e.g., structural, cultural, and institutional factors – requiring holistic, integrated approaches. Many factors need to be in place to maintain and increase diversity in research teams, including focus on equal access, work-life balance, freedom from gender biases, and supportive leadership.

2.5. Recruitment, onboarding and mentoring

The final section of this review examines different strategies used for recruitment, on-boarding, and mentoring as part of establishing and leading diverse scientific teams. Even though research on these topics is somewhat limited, several insights and recommendations can be drawn from the included literature.

Establishing well-functioning interdisciplinary teams involves recruitment with focus on non-traditional competences. In addition to traditional scientific competences, non-traditional competences include integration and translational expertise. Other non-traditional competences include communicative and collaborative skills and willingness to engage with practitioners and other stakeholders. These non-traditional competences cannot simply be recruited as part of the normal academic recruitment procedure but must be nurtured and cultivated as team members are brought in (Ding et al. 2020, Bammer 2020, Agrawal et al. 2020).

Similar recommendations are found in other parts of the literature. Banal-Estañol et al. (2019) and Deutsch et al. (2021) suggest recruiting outsiders rather than insiders, and placing "non-native" skills, values, and knowledge at the centre of the team to enable cross-fertilization and improved performance.

In some cases, it is helpful to include long-term collaborators as part of the team, since previous relationships "facilitate cross-disciplinary collaborative research by enabling trust and rapport to be built quickly", and through "pre-existing knowledge" creating new ways of working and thinking together (Ding et al. 2020, 7). Close collaborators share values, have a common language, and can optimize resources. However, the risk is that they lack innovative capacity and are unwilling to challenge tacit assumptions and established practices (Prager 2021).

For collaboration to flourish, several studies have shown that partners need to be brought onto the team early in the project life cycle to align objectives, expectations, and strategy (Bammer 2020, Boone et al. 2020, Ding et al. 2020, Deutsch et al. 2021). In other words, formulating a research strategy top-down and recruiting team members to join the team without giving them a mandate to challenge the strategy and co-develop the work programme may lead to suboptimal results. Building partnerships and establishing common research agendas take a significant amount of time (Vienni et al. 2020). Establishing an open and inclusive research culture ensures that early-career researchers have opportunities to contribute and that ideas of all team members regardless of rank and experience can contribute to shared problem solving (Ding et al. 2020, 7).

Mentoring is more elaborately discussed in the literature. For instance, it is emphasised that "strong mentoring, explicit incentives to engage, and guidance on best practices" are required to succeed in interdisciplinary science. Sharing leadership roles with junior researchers is important to optimise the utilisation of developing interdisciplinary practices (Boone et al. 2020, 1727).

Of course, principial investigators and research leaders must act as role models and mentors for junior researchers, but this does not prevent junior faculty members from having a say and participating in the leadership group. Accordingly, co-supervision and co-mentorship may be required. Indeed: "Initiating and maintaining cross-disciplinary research mentorship schemes and providing cross-disciplinary training through master's courses and PhD research projects are the groundwork for future cross-disciplinary research" (Ding et al. 2020, 8).

Judging from the available literature it is clear that determining the kinds of expertise needed to solve complex problems is a difficult task. In many ways, institutions of higher education appear to be in a

uniquely advantageous position in this regard, since they have very diverse resources in-house from which to assemble teams (Hart 2018, 30). How to optimally utilise these resources is still an open question, which calls for further empirical research. Such studies, and more generally any attempt to isolate individual variables for constructing successful research and innovation teams, are confronted by the entanglement of multiple and overlapping contextual and cultural factors. This problem of entanglement is further exacerbated with the inclusion of various kinds of stakeholders and co-producers of knowledge and solutions (Hart 2018, 31).

In conclusion, although questions regarding recruitment, onboarding, and mentoring are central for team science, it is a topic that requires further study. Identifying optimal collaborators and training programmes for scientific collaboration is a complex issue given the broad variety of tasks and skills involved in collaborative problem-solving. Even though a wide variety of approaches have been tested in the available literature (e.g., multi-mentoring models, retreats, and using mentors from outside the academy), more research is needed to determine optimal strategies and establish best practices (Su et al. 2015, Hall et al. 2018, Gordon et al. 2019).

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