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The Science and Practice of Team Science

Committee on Research and Application in Team Science

Board on Behavioral, Cognitive, and Sensory Sciences

Board on Human–Systems Integration

Division of Behavioral and Social Sciences and Education

Consensus Study Report

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This consensus study report was reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise. The purpose of this independent review is to provide candid and critical comments that will assist the National Academies of Sciences, Engineering, and Medicine in making each published report as sound as possible and to ensure that it meets the institutional standards for quality, objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.

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Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations of this report, nor did they see the final draft before its release. The review of this report was overseen by **JULIE RYAN,** Wyndrose Technical Group, and **JONATHAN MORENO,** University of Pennsylvania Health System. They were responsible for making certain that an independent examination of this report was carried out in accordance with the standards of the National Academies and that all review comments were carefully considered. Responsibility for the final content rests entirely with the authoring committee and the National Academies.

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Preface

This report highlights the growing importance of interdisciplinary collaboration, underscoring how modern scientific challenges often demand team-based approaches that integrate expertise from multiple fields. As contemporary research problems become more complex, no single discipline can address them fully, making team science critical for innovation. The National Academies of Sciences, Engineering, and Medicine's 2015 report, *Enhancing the Effectiveness of Team Science*, emphasized that over 90% of scientific and engineering publications were coauthored, illustrating the prominence of collaborative efforts. This new report builds on that foundation by addressing how recent developments—such as virtual collaboration and advancements in artificial intelligence—have reshaped the landscape of team science.

This report is particularly significant as it examines both the opportunities and challenges team science presents in today's rapidly evolving research environment. By investigating how to harness virtual and hybrid collaborations effectively, this report offers timely insights for best practices. It also addresses a critical need: preparing the scientific workforce with the skills, tools, and training it needs to navigate these collaborative environments. As such, this report provides valuable guidance for fostering effective, inclusive, and impactful team science, making it an essential resource for shaping the future of interdisciplinary research.

We wish to express our deep appreciation to the members of the committee for their diligent and dedicated contributions. Their expertise and knowledge were indispensable throughout our deliberations, and their efforts, which often required working nights and weekends, are particularly

notable given the incredibly challenging year it has been. We cannot thank them enough.

On behalf of the entire committee, we wish to thank the National Academies staff for their outstanding support and guidance. We are also deeply appreciative to Heather Kreidler for her writing and fact-checking, and the report benefited deeply from the editing skills of Joe Alper. Additionally, we want to express our sincere gratitude to everyone who contributed their time, expertise, and experiences to our committee. The presentations, resources, and insights contributed immensely to our deliberations. Finally, we wish to thank National Institutes of Health staff for their partnership and forthright participation throughout this process. We also thank the Keck Foundation for providing the funds for the committee to travel to in-person meetings.

Diana Burley and Mo Wang, *Co-Chairs*
Committee on Research and Application
in Team Science
June 2025

Acronyms and Abbreviations

ABCs	attitudes, behaviors, and cognitive states
AI	artificial intelligence
CBPR	community-based participatory research
COMPETES	Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science
CRediT	Contributor Roles Taxonomy
CTD	component team distance
CTSA	Clinical and Translational Science Award
CTSI	Clinical and Translational Science Institute
DoE	Department of Energy
EAGER	Early-Concept Grants for Exploratory Research
ERC	Engineering Research Center
FDA	Food and Drug Administration
GPU	graphics processing unit
HFE	human factors or ergonomics
IGERT	Integrative Graduate Education and Research Traineeship
IMOI	input-mediator-output-input
IRB	institutional review board

MOU	memorandum of understanding
NAKFI	National Academies Keck Futures Initiative
NCATS	National Center for Advancing Translational Sciences
NCI	National Cancer Institute
NIH	National Institutes of Health
NORDP	National Organization of Research Development Professionals
NRC	National Research Council
NRT	NSF Research Traineeship
NSF	National Science Foundation
OSF	Open Science Framework
R&D	research and development
SESYNC	Socio-Environmental Synthesis Center
STC	Science and Technology Centers
STEM	science, technology, engineering, and mathematics
STEMM	science, technology, engineering, mathematics, and medicine
TIP	Technology, Innovation and Partnerships (Directorate)
UN	United Nations

Summary

Modern scientific research frequently involves collaborative efforts, with teams tackling intricate problems that require integrating theories and methodologies from multiple scientific perspectives. Often, these science teams also reflect a wide range of demographic and geographic perspectives. Moreover, the challenges of managing large and complex teams, as well as growing interest in translating research findings for nonscientists, often means the teams include individuals who may not identify as scientists, such as administrators, funders, and community partners. Groundbreaking research, including the Human Genome Project, the discovery of the Higgs boson, and the invention of the internet, has been performed by science teams that vary in size, geographic distribution, and often disciplinary expertise.

A decade ago, the National Academies of Sciences, Engineering, and Medicine (National Academies) published *Enhancing the Effectiveness of Team Science*. That report substantially increased understanding of the importance of team science and highlighted the value of research on how team science is conducted and supported. However, shifts in the scientific and social landscape over the last decade—including technological developments, geopolitical tensions, and a global pandemic—have introduced new challenges for conducting team science.

Given those shifts and the growing importance of collaboration in modern scientific research, the National Academies Board on Behavioral, Cognitive, and Sensory Sciences and the Board on Human-Systems Integration, with support from the Keck Foundation and the National Institutes of Health, convened an expert committee to review and synthesize topics related to team science. The committee's statement of task covered five major topics:

1. Current team science practices, including in-person, virtual, and hybrid environments.
2. Evidence of best practices in team science and how to enhance those efforts.
3. What is known about the best practices, effectiveness, benefits, and potential pitfalls of virtual and hybrid approaches for team science.
4. What evidence-based approaches and training have been designed to enhance the effectiveness of team science.
5. What types of outcomes, methods, and measures would be appropriate for evaluating team science training and performance.

It is important to note the term "team science" is often applied ambiguously. It sometimes refers to the narrow study of science teams, at other times refers to the broader study of teams across disciplines and contexts, and can also refer to the conduct of science by teams. While the committee drew on findings from the general study of teams, this report focuses on science team practices and the study of those practices, using the terms *team science* and the *science of team science* to refer to those.

To address its statement of task, the committee sought to understand developments in the practice and study of team science in the decade since the 2015 National Academies report. It also aimed to identify evidence-based best practices for assembling and managing science teams. The committee reviewed the scholarly literature on teams generally and research on teams in the context of science. The committee members gathered expert insight through public forums and drew on their own expertise and experiences in analyzing what they learned from these sources. The committee found empirical investigations of a range of teams; however, the body of literature focused specifically on science teams is limited. Furthermore, the committee notes that science teams range from a pair of individuals with a relatively narrow scope of inquiry to massive, multiparty collections of collaborators addressing the world's most intractable problems. Thus, the committee provides the conclusions and recommendations in this report with the clear acknowledgment that team size, complexity, degree of disciplinary integration, proximity of team members, permeability of team boundaries, and other characteristics are critical aspects to consider when assessing whether and how to implement a particular best practice.

CURRENT STATE OF RESEARCH ON TEAM SCIENCE

The committee found that though recognition of its importance has increased over the last decade, the science of team science is not yet well developed. Moreover, while some institutions and funding agencies have increased their investment in research and initiatives on team science, the field remains underfunded. As a result, there is a disconnect between theory, empirical evidence, and accepted best practices for implementing team science initiatives and in the training programs that prepare team members. In addition, new technologies, including virtual and hybrid collaboration technologies and artificial intelligence tools, have emerged over the last decade and enable new forms of collaboration. Further investigation is required to understand how these technologies can affect team science dynamics, performance, and individuals, as well as best practices for how to effectively integrate new technologies into team science.

Research in the field is also hampered by differences in the use of terms when discussing team science. This includes terms such as *cross-disciplinary*, *interdisciplinary*, *multidisciplinary*, and *transdisciplinary*, which have unique meanings in relation to the study of team science but may be used interchangeably in other disciplines. With the broad array of parties involved in team science, including scholars of team science, researchers, and funders, this inconsistency can interfere with understanding key concepts in the field, confuse communication, and potentially reduce the effectiveness of team science initiatives.

Much of the research informing team science practices derives from findings in organizational psychology and other social sciences—that is, from the general study of teams, not from studies that specifically focus on science teams. Although some of the findings from that body of research may apply, science teams have unique characteristics and needs that may limit the generalizability of those findings from the broader team literature. Research is needed to better understand these potential differences.

BEST PRACTICES FOR CONDUCTING TEAM SCIENCE

Research on teams in general and on science teams specifically makes it clear that effective teams do not emerge naturally. Instead, the research points to several best practices or strategies that help science teams collaborate effectively to achieve their goals. These include practices that teams and their leaders can adopt, as well as strategies their supporting institutions can use to support strong science teams.

The committee identified best practices for science teams with two caveats. First, not all recommended practices will be suitable for every team. Science teams range from small groups that include members from one or two disciplines studying a relatively narrow question to large, cross-disciplinary teams tackling broad, complex issues. Teams differ in their goals and the complexity of the tools and methods they share. Thus, deciding on which practices will be appropriate will require careful analysis of the team's characteristics and objectives. Second, research on best practices for team science is in an early stage. Much of the available relevant research has been conducted on teams in general, rather than on science teams specifically, so careful attention is needed as to the applicability of the research findings.

Despite these caveats, the committee identified best practices for developing the competencies science teams require. Research has demonstrated that coordination, information-sharing, and conflict management are key processes for effective teams. In addition, three psychological states—cohesion, shared mental models, and transactive memory systems—are linked closely to achieving team objectives.

Education, training, and professional development—through workshops, formal and informal courses, and mentoring—are necessary to build these competencies. The committee relied on an existing framework to temporally organize its thinking about the practices for which there is reasonable evidence of effectiveness (from the general literature on teams as well as case studies) that will likely translate to the science team context. This four-part framework includes development, conceptualization, implementation, and translation. The following conclusion highlights some best practices the committee identified, but it is not exhaustive.

Conclusion 3-1: The following strategies offer the potential to improve science team performance and outcomes, if adapted to specific contexts and circumstances.

- *Development stage: careful team assembly that reflects a task analysis, consideration of the team composition, attention to the orientation of new members, and development of a shared language.*
- *Conceptualization stage: development of a team charter, deliberative team planning and project design, and attention to a shared mental model of the team's work.*
- *Implementation stage: systematic project management, regular team debriefs to identify what went well and what went poorly at each stage and to determine the best ways for the next project stage.*
- *Translation stage: working with community members and attention to external as well as internal validity, that is, understanding of the generalizability of the research findings.*

Recommendation 3-1: Research funders, including the National Science Foundation, the National Institutes of Health, and the many other agencies and foundations that support research, should provide resources enabling the study of team development, conceptualization, implementation, and translation.

BEST PRACTICES FOR EXTERNAL SUPPORT OF TEAM SCIENCE

Effective science teams require supports of many kinds. In addition to those the teams can adopt, there are many best practices that parties external to the team, including universities and other research institutions and funders, can implement to help facilitate both the study and practice of team science.

Published analyses and the views of the experts who presented to the committee suggest that current policies in most academic institutions, including those surrounding tenure and promotion, authorship, cost-sharing, allowable costs, and resource-sharing, do not incentivize participating in team science or research on team science. Similarly, many research funders do not support the activities or research needed for team science. Science journals, too, follow guidelines and practices that do not support team science or research on team science.

Conclusion 4-1: Institutions wishing to foster the study of team science would benefit from reviewing the incentive structures that influence individuals' decisions about engaging in such research. Specifically, many policies and practices that are currently in place surrounding tenure and promotion, authorship, cost-sharing, allowable costs, and resource-sharing appear to discourage engagement in the study of team science and participation in collaborative science teams. Institutional processes can also reinforce disparities in team science by failing to properly recognize work in team science, including community-engaged research and mentorship.

Recommendation 4-1: Academic departments should adapt their promotion and tenure processes to acknowledge and reward the contributions of researchers who take on the additional professional responsibilities associated with participating in and studying team science by:

a. recognizing and incorporating in tenure evaluations the valuable contributions made through different authorship roles, publications in interdisciplinary or nontraditional journals, and process-oriented outcomes.

b. ensuring that the demographic and disciplinary composition of promotion and tenure committees is both reflective and independent of

the candidates they are reviewing to the extent possible to facilitate increased representation in science team leadership.

c. revising criteria for selection to ensure fair consideration of candidates who research and team with underrepresented communities and/or do community-engaged research.

d. considering candidates' involvement in committees, initiatives, and other activities, including engagement outside the scientific community, that offer value to science teams and encourage participation.

e. reviewing the promotion and tenure process periodically, for instance every several years, to ensure continuous improvement and minimize inefficiencies.

Recommendation 4-2: Science journal editors should establish comprehensive systems and policies to build team science into the publishing mainstream, including:

a. conducting a systematic assessment to identify barriers that may limit the incorporation of team science literature in their journal. These findings should be used to develop actionable strategies to address identified barriers.

b. adopting clear policies and guidelines for authorship, allocation of credit, and contribution level, particularly when there are many contributing authors and when authors are contributing from different disciplines with different authorship practices. Policies can include strategies for addressing authorship disputes.

c. allocating appropriate space to publish research on the science of team science.

The funders of scientific research can play a key role in fostering both conduct of team science and the study of its operation and outcomes.

Recommendation 4-3: Funders of team science, including the National Science Foundation, the National Institutes of Health, and the many other agencies and foundations that support research, should integrate team science needs into funding programs and policies and should remove barriers to team science efficacy by:

a. including team science needs, such as team-building, travel and meetings, professional development and training, and resource-sharing in allowable costs.

b. allowing for the inclusion of nonscientist team members and leaders in the project budget to allow for the compensation of their time.

Institutions that host team science initiatives can implement many measures to support their scientific collaborators directly.

Recommendation 4-4: Institutions seeking to advance team science effectiveness should allocate resources to support science teams. Resource allocation may cover, but is not limited to the following:

a. resources that mitigate the operational burden on science teams by investing in the support of administrative staff.

b. training and mentorship for research administrative staff working on team science projects.

c. resources to expand access to and the use of technologies that optimize team participation for geographically dispersed members.

d. funding to address gaps in the physical, digital, and procedural environment. This could include applying universal design principles that accommodate the needs of all individuals.

RESEARCH AND EVALUATION NEEDS

Despite the importance of team science, many questions about how it is best done and supported cannot yet be answered with full confidence. More robust collection of data on science teams and their work are needed, as well as evaluation of their operation. The committee found that the existing body of evaluation and research on team science tends to emphasize objective and archival measures of team performance output, especially the publications science teams produce, and tends to underemphasize evaluation of ongoing team functioning, the effect of team science on individual members, and other forms of team performance output.

Systematic evaluation of science teams can foster improvements in team science initiatives and best practices for science teams, although the evolving nature of science teams makes a one-size-fits-all approach to evaluation inadequate. However, data collection and evaluation of key elements will be important both for strengthening individual teams and for strengthening research on science team functioning.

Conclusion 5-1: Data collection and evaluation, supported by both institutions and science team leaders, are critical for answering questions about key features of science teams:

- *How social processes on the team are unfolding (e.g., team members' perception of experiences of participation on the team, team member satisfaction, psychological safety, trust).*
- *What the team is producing (e.g., successfully completed team objectives, publications, patents and invention reports, research grant applications and awards, educational outcomes).*
- *What impact the team is having on individual members (e.g., well-being, skill and knowledge advancement, growth of professional networks, career success).*

Recommendation 5-1: Funding agencies, including the National Science Foundation, the National Institutes of Health, and the many other agencies and foundations that support research, should require that the science teams they support develop an evaluation plan to assess their effectiveness and impact. The plans should incorporate team dynamics (e.g., social processes), team performance (e.g., bibliometric metrics), and impact on members (e.g., learning and development outcomes). Regular review periods should be established with the team to monitor and track progress and team effectiveness.

Researchers studying the science of team science continue to make progress in theoretical developments and are applying those theories to specific case studies. For the field to move forward, additional work is needed to develop a robust, empirical evidence base for identifying best practices and institutional supports. Many principles and concepts from the study of teams in general (e.g., from researchers in social and organizational psychology, organizational behavior, cognitive science) are likely to be useful in the context of team science, but the empirical basis for applying these insights to science teams is still limited. Addressing this gap is crucial, as science teams have unique features, raising concerns about the generalizability of these findings.

Conclusion 6-1: The research translating findings on the functioning of teams general to the functioning of science teams is incomplete for reasons that include insufficient funding and a lack of professional recognition and reward for the study of science teams. Specifically needed are:

- *Studies focused on the science team context that explore the application of existing theories to the unique processes and dynamics that distinguish science teams from traditional organizational teams.*
- *Studies of team science competencies and interventions that allow for robust statistical analyses or pre- and post-testing to build the empirical evidence base for team science learning, training, and professional development in real time.*
- *Data-driven research, including longitudinal studies, to better understand team science outcomes.*
- *Research to identify and investigate institutional policies and practices that reinforce or serve as barriers to team science, such as the support structures universities can provide (e.g., research development professionals, team facilitators), how these affect team science processes and outcomes, and other incentives that influence the conduct of team science.*

- *Research into the effectiveness of virtual collaboration tools and how these relate to the specific configuration of hybrid and virtual teams, including factors such as geographic distribution, temporal dynamics, and communication needs.*

Recommendation 6-1: Funders interested in supporting the conduct of science should prioritize research on, and provide sufficient funding for, the application of findings from the broader study of teams to the science context. Areas of prioritization may include but are not limited to studies that incorporate both qualitative and quantitative data to build empirical evidence about the science context and research evaluating institutional policies and supports for science teams.

1

Introduction

Scientific research has gravitated increasingly toward collaborative research, as contemporary scientific problems often require solutions that draw from multiple areas of expertise. *Team science*, defined as collaborative, interdependent research conducted by more than one individual, is becoming the norm as it often involves integrating scientific approaches to solve problems that are multifaceted, multidimensional, interdependent, and do not have a single answer. Critically, team science includes project teams and more complicated collections of researchers, such as multiteam systems that operate within research centers, initiatives, and networks. Team science also considers the engagement of input beyond researchers, such as community members and leaders, policymakers and other decision-makers, caregivers, health care providers, and research administrative professionals. To prepare a workforce that can participate effectively in team science, it is critical to equip researchers and their administrative team members with training on evidence-based tools and strategies for engaging in team science. The nascent field of the science of team science aims to generate and build on the empirical evidence base (e.g., National Research Council, 2015) and translate that knowledge to enhance the effectiveness of team science in practice.

Evidence suggests that team science approaches often lead to results with greater impact and innovation relative to single-investigator approaches (Lee et al., 2015; Wuchty et al., 2007). Boundary-spanning teams that cross disciplines, organization structures, or geographic distances are particularly effective, often yielding better outcomes, increased productivity, and greater scientific impact (Hall et al., 2018). Although there are many benefits of collaborative research efforts that leverage the strengths and varied perspectives of scientists, team science approaches can also lead to significant challenges as researchers try to integrate effectively across fields that may have different approaches, methodologies, and concerns. Moreover, science teams are frequently spread across different locations, and team members may have different disciplinary or demographic backgrounds. Consequently, the *science of team science* has emerged as a research area in which scholars from various disciplines, such as psychology, organizational sciences, sociology, communication, and philosophy, contribute conceptually and empirically to understanding how science teams are organized and work together, how to best measure their effectiveness, and the implications of individual differences in team science.

Understanding how to best develop and facilitate the work of science teams is part of a broader motivation to understand science, scientists, and the context in which scientists practice. Many areas of scholarship share this motivation, ranging from the history and philosophy of science; science and technology studies; and, more recently, the science of science. These areas all examine different science concepts, processes, and outcomes. Some study science to add to the understanding of science, while others also seek out ways to improve the science ecosystem. To varying degrees, each has also studied collaboration in science, but rarely as a focal issue of inquiry. Because of this, the science of team science was developed specifically to pursue a scholarly examination of teamwork in science (Hall et al., 2008).

The goal of the science of team science is to improve the understanding of how scientists interact as members of a science team and how their collaboration helps build and integrate knowledge across disciplinary, professional, and institutional boundaries (Stokols et al., 2008). From this improved understanding, the science of team science aims to help science teams make full use of their integrative capacity—"the social and cognitive processes, along with emergent states, that shape a team's ability to combine diverse knowledge" (Salazar et al., 2012, p. 527). Fundamental to this goal is reframing science collaboration as a process of teamwork to be mastered (Fiore, 2008). In contrast to related fields, science teams are the focal area of study in the science of team science to improve fundamental understanding of the collaborative production of knowledge and develop new methods and models to improve teamwork on science teams.

To better conceptualize the collaborative component of team science, it is useful to follow a distinction developed in the organizational sciences that distinguishes between team and task competencies (Fiore et al., 2019). *Taskwork* refers to the activities associated with achieving a team's goals. Examples of taskwork in science include experimental design, data collection, and statistical analysis. *Teamwork,* on the other hand, involves the interactions among team members that are essential for effective collaboration. In science, this includes communicating clearly about complex ideas, managing coordination needs, and understanding and using teammate expertise. For science teams to succeed, they need to develop competencies relevant to both taskwork and teamwork. As such, a wide range of competencies encompassing the knowledge, skills, and attitudes that facilitate team science is necessary for success in scientific collaborations (Fiore et al., 2019).

STUDY BACKGROUND AND CHARGE TO THE COMMITTEE

In 2015, the National Academies of Sciences, Engineering, and Medicine (National Academies) released the report *Enhancing the Effectiveness of Team Science* (National Research Council, 2015). That consensus report synthesized findings from research on teams and factors that bear on the success of team science endeavors, offering recommendations for improving team science effectiveness and identifying several areas for further research. In the decade since, new developments have reshaped the landscape of team science. For example, the COVID-19 pandemic fostered new dimensions of virtual collaboration, given the need to shelter in place, which changed working conditions and arrangements across the globe. Emerging technologies and recent innovations in the realm of artificial intelligence (AI) also add a new dimension to team science. These tools can change the nature of collaboration processes and the dynamics of collaboration when collaborators are not limited to human team members (National Academies of Sciences, Engineering, and Medicine, 2022). Variations in human–machine teaming structures raise additional dimensions of team science to consider. Finally, the number of authors contributing on scientific journal articles has continued to increase in the years following the 2015 report, reflecting an increase in science team sizes (e.g., An et al., 2020; Paul et al., 2024).

Consequently, 17 institutes and centers at the National Institutes of Health[1] and the W. M. Keck Foundation requested a consensus study to explore the state of the science of team science in light of its growing relevance and the changing landscape in contemporary scientific endeavors. This

[1] These include the Sexual & Gender Minority Research Office, National Institute of Neurological Disorders and Stroke (NINDS) BRAIN Initiative, NINDS, National Center for Advancing Translational Sciences, Environmental Influences on Child Health Outcomes Program, National Institute of Mental Health, National Cancer Institute, Chief Officer for Scientific Workforce Diversity, National Institute on Aging, Fogarty International Center, National Institute of General Medical Sciences, National Institute of Nursing Research, National Institute of Biomedical Imaging and Bioengineering, National Institute of Arthritis and Musculoskeletal and Skin Diseases, National Institute of Environmental Health Sciences, Office of Disease Prevention, and Office of Behavioral and Social Sciences Research.

consensus study (a) explores team science, including best practices, barriers, effects, and the role of virtual and hybrid environments; (b) develops a contemporary understanding of best practices in team science; (c) evaluates the growing role of virtual and hybrid teams; (d) identifies gaps in resources and training for team science; and (e) explores how to best measure the effectiveness of teams. The full statement of task for the committee can be found in Box 1-1.

BOX 1-1
Statement of Task

The National Academies will convene an ad hoc, diverse committee of approximately 12–15 scholars, practitioners, and other experts to evaluate the current state of the science of team science and multidisciplinary collaborations across different scales and environments. The committee will meet, conduct public workshops, review the literature, deliberate, and then publish a consensus report of its findings, conclusions, and recommendations. Included will be forward-looking research recommendations (research gaps and infrastructure needs) and suggested applications and/or best practices for a variety of settings and scales. Following publication, dissemination activities, such as a public-facing webinar should take place to promote the report.

The committee will consider reviewing and synthesizing information related to the following topics:

- **The effectiveness, benefits, and potential pitfalls of virtual and hybrid approaches for team science.** Are there models of collaboration outside of science that might inform best practices? What collaborative technologies are best suited for virtual and hybrid collaboration and how might these vary depending on the dimensions of team science, including the scale of the team, types of collaborators, degree of disciplinary integration, proximity of team members, permeability of team boundaries, disciplinary and form of research, and domains of research involved? What are best practices for working in the hybrid, virtual, and in-person work environment(s) and how might these vary depending on the dimensions of team science?
- **Evidence-based approaches and training that have been designed to enhance the effectiveness of team science and identify any gaps in resources and guidance.** What methods have been employed and who was the target audience? What types of outcomes, methods, and measures are appropriate for evaluating team science training? What are best practices for training and/or optimizing teams that include various types of non-scientist team members?
- **Evidence of best practices in team science and how to enhance those efforts.** What are the current team science best practices? What research is needed to further evaluate and enhance these practices?

To address this charge, the National Academies appointed an ad hoc committee with a broad range of expertise, including individuals with backgrounds in the science of team science, behavioral and social science, virtual platforms and collaborative tools, AI and emerging technologies, science policy and scientific research, individual differences, ethics and/or risk management, communication, business and management, industrial and organizational psychology, and related fields. Appendix A provides biographies of the 13 committee members.

COMMITTEE APPROACH

The committee's approach to its charge consisted of a review of the evidence in the scientific literature and several other information-gathering activities. In reviewing the literature and formulating its conclusions and recommendations, the committee considered information from public presentations, targeted literature searches, and committee expertise. The committee drew from the team science literature when available, supplemented by team research in other organizational contexts including business and health care. The committee heard from multiple presenters on various topics related to the statement of task. These public information-gathering sessions included speakers from academic communities, research organizations, and funding agencies. The presentations covered topics such as participation and user-friendliness; ethics in team science; evaluation of team science approaches; and practical reflections from researchers, administrators, and funders in the team science ecosystem. To augment this report, the committee commissioned two papers, one on the topic of AI in team science and the other on the topic of disability and accessibility in team science.[2] To address the charge, the committee sought to understand developments in the study and practice of team science over the last decade, including increased awareness of team science practices in multiple fields and examining new programs for supporting team science. The committee chose to define a science team member broadly as including any person in a science team working toward a shared goal. This can include, but is not limited to, technicians, support staff, engineers, students, and participating members of the community. The committee also aimed to examine the role of individual differences in team science—identifying both enabling and inhibiting factors in the integration of individuals in teams. In addition, it sought to review team science best practices and their supporting evidence, how such practices are currently supported and could be strengthened, and the means of evaluating team science outcomes and impact.

[2] Commissioned papers and more information are available at https://www.nationalacademies.org/our-work/research-and-application-in-team-science

Identifying Interested Parties

Identifying interested parties in team science is important for providing clarity and focus to team science initiatives, understanding how best to allocate resources, and building accountability and trust around the work conducted by team scientists, as well as for ethical considerations. *Interested parties* include individuals (e.g., researchers, scientists, administrators, policymakers, community members, patients and patient advocates) and institutions (e.g., funding agencies, academic institutions, national laboratories, nonprofit and industry partners; see Box 1-2). These interested parties form an interconnected ecosystem conducting and supporting science, and each may require different skills and competencies. Those conducting team science are focused on addressing pressing societal issues, advancing knowledge, and finding innovative solutions to problems that are too broad for individual researchers to tackle alone.

BOX 1-2
Interested Parties Relevant to Team Science

- **Researcher:** The term *researcher* describes any member of a science team conducting and disseminating scientific research. This could be a faculty member running their own laboratory, a scientist in a private-sector research and development section, someone working at a national laboratory (e.g., Sandia National Labs), or a community member. It could also include researchers in training, such as graduate students or postdocs.
- **Science Team Leader:** A *science team leader* could be a director of an academic laboratory or research institute, or anyone in a leadership position in the public or private sectors who oversees research projects. The setting of the research varies, ranging from wet labs to communities.
- **Facilitator:** A *facilitator* is a blanket term used to describe those who support various aspects of the science process. These individuals may provide episodic guidance on a specific project phase, such as ideation or proposal development, or they may engage with the science team continuously throughout the research process.
- **Evaluator:** The term *evaluator* encompasses those who have an interest in, or are responsible for, assessing the effectiveness of team science processes, outcomes, and contextual influences. Evaluators are often external to the team to give unbiased perspectives.
- **Community Member:** This report uses the term *community member* generally to describe those individuals on a team who may or may not be professionally trained scientists but participate in research—both in defining the problems to be solved and in developing solutions—requiring input and guidance from those directly affected, such as patients, family members, local business owners, and politicians.

BOX 1-2 Continued

- **Science Administrator:** *Science administrators* might have some overlap in responsibilities with a science leader, but this report uses the term to differentiate those whose responsibilities do not necessarily involve direct oversight of research projects, such as institute directors and grant administrators.
- **Institution:** *Institution* refers to a variety of organizations, such as academic institutions, national laboratories, and industry research and development offices.
- **Funding Agency:** *Funding agency* refers to a public funding agency or a private philanthropic organization supporting science.
- **Policymaker:** *Policymakers* are individuals or groups responsible for creating, shaping, and implementing laws, regulations, and public policies that govern societies.
- **Science of Team Science Scholar:** *Science of team science scholars* use various research methods to study teamwork within, external to the science team context, or both; this contains, but is not limited to, social scientists conducting research to examine fundamental questions about science team processes, humanities scholars studying how different epistemological worldviews alter the questions cross-disciplinary teams develop, and those studying how educational programs or professional development interventions improve science team member competencies for collaboration.
- **Research Translator:** *Research translators* are those who bridge the gap between scientific innovation and its application to policy or practice. These professionals often work in the innovation offices of a research institute or enterprise entity, serving as the conduit through which research findings are transformed into patents, products, and other actionable solutions.

The science ecosystem comprises researchers, science team leaders, facilitators, evaluators, and science administrators who collaborate to address scientific questions. These professionals develop crucial team science competencies both during training and while leading collaborative initiatives.

Community members represent another vital component of the science ecosystem. These individuals and groups bring valuable lived experiences that inform research solutions and the problems to be solved, including both research questions and constraints (Corburn, 2007; Wandersman, 2003). Their contributions extend beyond simply providing data and context, as they actively participate in the research process and are affected directly by the outcomes of team science endeavors, whether those effects are positive or negative.

In this context, *institution* refers to a variety of organizations, including academic institutions, national laboratories, and industry research and development offices. Institutional members can support team science initiatives by providing the resources, infrastructure, and administrative support necessary to conduct team science.

Another group of interested parties includes research translators who bridge the gap between scientific innovation and its application to policy and practice. These professionals often work in innovation offices, serving as the conduit through which research findings are transformed into patents, products, services, and other practical solutions or policy recommendations. Research translators possess a unique blend of scientific knowledge, business acumen, and communication skills, enabling them to facilitate communication between science teams and the intended recipients of the scientific discovery. They work closely with scientists, often as members of the research team, to comprehend the nuances of the research and to distill complex findings into accessible language that interested parties can readily understand. In some cases, this role involves guiding the research process to align with industry needs and navigating the patent landscape to secure intellectual property rights. In other situations, research translators may outline how the innovation can be used to evolve policy recommendations.

Funding agencies (e.g., government agencies, nonprofit foundations, private-sector entities) may provide financial support for science teams to conduct research, seek out innovative breakthroughs, advance science, and help society. It is important for funding agencies to understand what it takes to conduct team science so that they are aware of how best to structure funding mechanisms.

Policymakers use the findings produced by science teams to develop their reports and arguments for making changes to policy. With the research produced, they make informed, justifiable, and strategic decisions while also providing a foundation for accountability and evaluation. The research produced helps frame issues, assess risks and impacts, and build strong arguments by offering proof of existing problems or the success of interventions. Comparative studies guide policymakers in learning from other regions, while research also justifies budget allocations by showing where resources can be used most effectively.

Finally, science of team science scholars use various research methods to study teamwork within and external to the science team context.

Terminology

Terminology in the science of team science is used inconsistently, often leading to confusion. For example, the term *team science* is often applied ambiguously, sometimes referring narrowly to the study of science teams and at other times, to the broader science of teams across disciplines. This lack of precision can lead to misunderstandings among researchers, practitioners, and funders who engage with the team science literature. Scholars in the field frequently report that this lack of clarity in terminology not only hampers communication but also potentially impedes interdisciplinary collaboration by creating differing expectations and interpretations of shared research goals.

Adding to this challenge is the inconsistent use of such terms as *cross-disciplinary*, *interdisciplinary*, *multidisciplinary*, and *transdisciplinary*. Although these terms each describe specific types of collaborative approaches in team science, they are often conflated or used interchangeably across disciplines. Within the science of team science, these terms have been defined to delineate distinct levels of integration, interdependence, communication, and coordination among team members from different disciplines. For example, *multidisciplinary teams* typically draw from various fields without integrating knowledge deeply, while *transdisciplinary teams* aim for seamless integration of disciplinary perspectives. However, in other scientific fields, these terms are not always used with such precision, leading to potential misalignment when teams from multiple disciplines collaborate. See Box 1-3 for these definitions and Appendix B for further discussion.

Inconsistent terminology can affect funding decisions, grant evaluation processes, and team formation strategies, potentially reducing the effectiveness of funded initiatives. By striving for consistency in the use of terms, team science scholars and funders can promote clearer communication and set uniform expectations for research crossing disciplines. Clear, standardized terminology will improve understanding within the field and contribute to more productive partnerships and innovative approaches in research that spans multiple scientific domains.

BOX 1-3
Definitions of Collaborative Approaches

- **Cross-disciplinary:** *Cross-disciplinary* research refers to collaboration among multiple disciplines toward a shared objective.
- **Interdisciplinary:** In *interdisciplinary* research, concepts are blended or juxtaposed from different disciplines.
- **Multidisciplinary:** In *multidisciplinary* research, each discipline makes separate contributions in an additive way.
- **Transdisciplinary:** *Transdisciplinary* research involves the advancement and integration of discipline-specific theories, concepts, and methods.

ORGANIZATION OF THE REPORT

This report provides a comprehensive overview of team science and cross-disciplinary collaborations.

Chapter 2 delves into a review of the current state of the science of team science, beginning with a discussion of its definition and evolution. It highlights key findings from previous reports and assesses progress made since their publication. It also examines emerging changes in the team science landscape and practices, as well as unanticipated developments.

Chapter 3 considers best practices for team science and their effectiveness and supporting evidence base. The chapter begins by discussing education, training, and professional development. The second part of the chapter discusses best practices for supporting science teams, looking closely at the key areas of development, conceptualization, implementation, and translation.

Chapter 4 considers best practices for external support for team science. The chapter discusses exploring institutional policies related to tenure, promotion, and credit for team science contributions, alongside considerations for material and data sharing, ethical approvals, compliance, and staffing needs. The chapter also delves into infrastructure requirements, funding considerations, and incentives and reward structures within the broader community.

Chapter 5 focuses on appropriate ways to evaluate the processes and outcomes of team science and its effect on interested parties. The chapter delineates proximal and distal outcomes for individuals, teams, institutions, science, and society, emphasizing factors such as affective, behavioral, and cognitive processes, as well as broader societal impacts such as community engagement and solutions to pressing global challenges.

Chapter 6 focuses on identifying research gaps, synthesizing what the committee has learned and presenting its overarching conclusions and recommendations.

Finally, five appendices correspond to the content of the report: Appendix A includes committee member biosketches, Appendix B gives background on the science of team science, Appendix C gives an overview of the factors and characteristics of effective teams, Appendix D provides a sampling of survey-based assessments in the literature on teams, and Appendix E contains a glossary.

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2

Review of Current Science of Team Science

Key findings from a previous National Academies of Sciences, Engineering, and Medicine (National Academies) consensus report, *Enhancing the Effectiveness of Team Science*, aimed to deepen understanding of science teamwork (National Research Council, 2015). This chapter reviews those findings and addresses changes in the team science landscape emerging since the previous report's release, drawing on materials from the committee's information-gathering sessions. The chapter also considers how key recommendations from the 2015 report have been implemented.

KEY TAKEAWAYS FROM *ENHANCING THE EFFECTIVENESS OF TEAM SCIENCE*

The committee for the 2015 report was charged with conducting a consensus study to recommend strategies for enhancing the effectiveness of team science and exploring factors that affect science team dynamics, effectiveness, and productivity (National Research Council, 2015). Through a literature review and expert presentations, the committee examined factors at the team, center, and institute levels to understand their influence on science team effectiveness. In addition, the consensus study explored various management approaches and leadership styles that affect science team effectiveness. The committee also reviewed how tenure and promotion policies help or hinder academic researchers who participate in research teams. Finally, the committee considered organizational factors, such as human resources policies and cyberinfrastructure, as well as organizational structures, policies, and practices, that might impact the effectiveness of science teams.

At the outset, the National Academies committee identified a set of key features that pose challenges for science teams (National Research Council, 2015). These features include a highly varied membership, which can lead to differing perspectives and approaches that can sometimes complicate collaboration. Science teams often need deep knowledge integration arising from the goal of merging disparate expertise and disciplinary backgrounds (National Research Council, 2015).

Some science teams experience permeable boundaries, where membership may change and adapt depending on phases of the project. This can result in ambiguity regarding roles and responsibilities and in the amount each team member is expected to contribute to a given project phase. High task interdependence often requires close coordination and cooperation among team members to achieve shared objectives.

Furthermore, large science teams often face difficulties with complex coordination and communication (National Research Council, 2015). As the 2015 report noted, large science teams often better reflect structures known as multiteam systems in the field of organizational science (Zaccaro et al., 2011). *Multiteam systems* are interdependent sets of two or more component teams pursuing shared superordinate goals; they offer multiple benefits, including resource capacity, flexibility, and component team specialization (Mathieu et al., 2002; Shuffler & Carter, 2018). However, multiteam system coordination can be extremely challenging given the large size, complexity, and dynamism of these systems. Moreover, multiteam systems often experience goal misalignments within or across teams, which can hinder collaboration and cohesion across the research environment. Geographic dispersion adds another layer of complexity, requiring effective virtual communication and coordination mechanisms.

To address these types of challenges, the 2015 committee considered the broad body of literature in, and experts from, the social sciences to understand findings on teams and organizations (National Research Council, 2015). It highlighted the robust body of research on teamwork going back decades that shows how team processes relate to team effectiveness. The committee identified interventions, focused on team composition, development, and leadership, that support teamwork and provide a route to enhancing team effectiveness.

Other interventions can further enhance team science outcomes, such as improving virtual collaboration practices and technologies, revising promotion and tenure criteria to recognize team-based contributions, and increasing support from funding agencies to study the science of team science (National Research Council, 2015). By implementing the 2015 report recommendations, the broader scientific ecosystem can foster an environment more conducive to collaborative research and maximize the impact of team science.

The 2015 report provided nine recommendations covering the areas of team composition, team professional development, leadership for team science, supporting virtual collaboration, organizational supports for team science, funding for team science, and finally advancing research on the effectiveness of team science (National Research Council, 2015). Box 2-1 lists the recommended actions from the 2015 report, and Appendix B includes additional details about the key takeaways from the 2015 report.

BOX 2-1
Recommendations from
Enhancing the Effectiveness of Team Science

Recommendation 1: Team science leaders and others involved in assembling science teams and larger groups should consider making use of task analytic methods (e.g., task analysis, cognitive modeling, job analysis, cognitive work analysis) and tools that help identify the knowledge, skills, and attitudes required for effective performance of the project so that task-related diversity among team or group members can best match project needs. They should also consider applying tools such as research networking systems designed to facilitate assembly of science teams and partner with researchers to evaluate and refine these tools and task analytic methods.

Recommendation 2: Team-training researchers, universities, and science team leaders should partner to translate, extend, and evaluate the promising training strategies, shown to improve the effectiveness of teams in other contexts, to create professional development opportunities for science teams.

Recommendation 3: Leadership researchers, universities, and leaders of team science projects should partner to translate and extend the leadership literature to create and evaluate science leadership development opportunities for team science leaders and funding agency program officers.

Recommendation 4: Leaders of geographically dispersed science teams and larger groups should provide activities shown by research to help all participants develop shared knowledge (e.g., a common vocabulary and work style). These activities should include team professional development opportunities that promote knowledge sharing (see Recommendation #2 above). Leaders should also consider the feasibility of assigning some tasks to semi-independent units at each location to reduce the burden of constant electronic communication.

Recommendation 5: When selecting technologies to support virtual science teams or larger groups, leaders should carefully evaluate the needs of the project, and the ability of the individual participants to embrace new technologies. Organizations should promote human-centered collaboration technologies, provide technical staff, and encourage use of the technologies by providing ongoing training and technology support.

continued

BOX 2-1 Continued

Recommendation 6: Universities and disciplinary associations should proactively develop and evaluate broad principles and more specific criteria for allocating credit for team-based work to assist promotion and tenure committees in reviewing candidates.

Recommendation 7: Funders should work with the scientific community to encourage the development and implementation of new collaborative models, such as research networks and consortia; new team science incentives, such as academic rewards for team-based research (see Recommendation #6); and resources (e.g., online repositories of information on improving the effectiveness of team science and training modules).

Recommendation 8: Funders should require proposals for team-based research to present collaboration plans and provide guidance to scientists for the inclusion of these plans in their proposals, as well as guidance and criteria for reviewers' evaluation of these plans. Funders should also require authors of proposals for interdisciplinary or transdisciplinary research projects to specify how they will integrate disciplinary perspectives and methods throughout the life of the research project.

Recommendation 9: Public and private funders should support research on team science effectiveness through funding. As critical first steps, they should support ongoing evaluation and refinement of the interventions and policies recommended above and research on the role of scientific organizations (e.g., research centers, networks) in supporting science teams and larger groups. They should also collaborate with universities and the scientific community to facilitate researchers' access to key team science personnel and datasets.

SOURCE: Excerpted from National Research Council, 2015, pp. 8–13.

IMPLEMENTING THE 2015 RECOMMENDATIONS: SUCCESSES AND CHALLENGES

The 2015 report applied research on team dynamics from various other disciplines, including organizational behavior and industrial-organizational psychology to the context of science teams (National Research Council, 2015). It thus laid the foundation for both scholars and practitioners to leverage this knowledge to enhance the effectiveness of science teams. Over the subsequent decade, the report has been downloaded over 31,000 times as of the summer of 2024 and by people in countries around the world, including from China, Canada, the United Kingdom, and Australia, demonstrating the international appeal of team science.[1] The report's broad reach

[1] Outreach data provided by National Academies Press, as of October 16, 2024 (National Research Council, 2015).

can also be seen in the actions of team science advocates, such as scholars, practitioners, funders, and administrators, operating at various levels in the science ecosystem.

Although the report spurred many changes, the committee for the present study identified factors that have shaped and influenced various aspects of team science over the past decade. As Chapter 1 noted, these include societal changes arising from the COVID-19 pandemic as well as increased use and sophistication of technologies such as virtual collaboration tools and generative artificial intelligence (AI). As such, the current report considers these additional factors.

Indicators of Success

One of the primary purposes of the 2015 report was to increase the recognition of team science in scientific collaborations (National Research Council, 2015). This has been one of the clearest indicators of that report's success, with influence on disciplines including biology (Full et al., 2015), health and medicine (Czajkowski et al., 2016; Hall et al., 2020; Little et al., 2017; Sargent et al., 2022), earth and environmental sciences (Gilligan, 2021; Lanier et al., 2018; Maxwell et al., 2019; Pennington et al., 2016; Wallen et al., 2019), organizational science (Burt et al., 2022; Fiore et al., 2018; Guise et al., 2017), psychology (Haynes et al., 2019; Tebes, 2018; Tebes & Thai, 2018), nursing (Conn et al., 2019), engineering (Roscoe et al., 2019), sustainability (Killion et al., 2018; von Wehrden et al., 2019), human factors (Gupta & Woolley, 2021), clinical and translational science (Pelfrey et al., 2021; Rolland et al., 2021; Vogel et al., 2021), and physics (Halford et al., 2023)—all have promoted team science principles as a mechanism for advancing their fields. This broad acceptance signifies a shift in perspective, where those conducting science acknowledge the value of cross-pollinating research. Although specialization remains crucial, scholars in many fields now recognize that significant scientific progress can be achieved through cross-disciplinary collaboration and by applying team science principles. Publications in multiple disciplines have emphasized the benefits of team science, which has helped to change the culture and approach to scientific research by promoting the integration of varied expertise and perspectives (Fiore et al., 2019; Lotrecchiano et al., 2023).

Another clear indicator of success is the growing recognition that tenure and promotion materials need to account for how the success metrics of effective collaboration differ from traditional guidelines (Brody et al., 2019; Cline et al., 2020; McHale et al., 2019; Meurer et al., 2023; Rohrbach & Genco, 2022). The engagement of junior scholars in cross-disciplinary team science can depend heavily on the incentive structures the university system provides. Without language that acknowledges participation in team science—such as recognition for publishing in journals outside one's primary discipline, differences in authorship practices across disciplines, and participation as a co-investigator on large extramural funding efforts—junior scholars may be less inclined to engage in meaningful cross-disciplinary collaborations. Although there is still a long way to go in these efforts, recognizing that the reward structure for tenure and promotion needs to evolve is an important step forward.

The 2015 committee also noted that many research institutions had initiated efforts to promote applying team science principles (National Research Council, 2015). In the last decade, more institutions have created internal funding opportunities that promote and require translational research or research from cross-disciplinary teams.[2] In addition, several academic institutions have made significant investments in programs to improve collaboration within science teams. These prominent programs in clinical and translational science focus on equipping researchers with essential skills such as communication, conflict resolution, and leadership, often using the recommendations from the 2015 report in their training and guidance.[3] In addition, dedicated laboratories, such as the University of California, Irvine's Team Scholarship Acceleration Lab,[4] focus on promoting and applying team science principles. Such programs help science teams develop by providing talks and lunch-and-learn sessions, creating collaboration plans, offering team science training toolkits, and consulting on grant proposals. These efforts have enhanced collaboration within institutions and fostered a culture that values interdisciplinary research and teamwork.

The 2015 report was also successful in informing funding agencies, which have bolstered their support for team science initiatives (National Research Council, 2015). Whether directly or indirectly, team science is being promoted by those seeking to support complex collaborations. For example, center-level research at the National Science Foundation (NSF), including its Science and Technology Centers,[5] Engineering Research Centers,[6] Synthesis Centers,[7] and Convergence Accelerators programs, has

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[2] For examples, see the Signature Research Initiative Program at American University (https://www.american.edu/research/sri.cfm), Global Grand Challenges at Cornell University (https://global.cornell.edu/global-grand-challenge/about), and funding initiatives at Virginia Commonwealth University (https://onevcuresearch.vcu.edu/funding/).

[3] See, for example, the Center for Clinical & Translational Science & Training (https://www.cctst.org/team-science-training) and TeamMAPPS (https://teammapps.utmb.edu/).

[4] More information about the Team Scholarship Acceleration Lab is available at https://tsal.uci.edu

[5] See, for example, the Center for Chemical Currencies of a Microbial Planet (https://ccomp-stc.org/).

[6] See, for example, the Center for Smart Streetscape (https://cs3-erc.org/).

[7] See, for example, the National Synthesis Center for Emergence in the Molecular and Cellular Sciences (https://ncems.psu.edu/).

incorporated tenets of the science of team science. Many calls for proposals at NSF describe the requirements for a team-based approach to conducting center-level research, with an expectation that grant applications articulate roles clearly and describe the interdependencies of the research initiatives. Also relevant is NSF's Research Traineeship (NRT) program,[8] which, for the past decade, has worked to improve education for graduate students. More recently, it has moved beyond only addressing the requisite knowledge, skills, and attitudes for science, technology, engineering, and mathematics (STEM) careers. Now it also emphasizes training graduate students so that they can collaborate across disciplines. The 2024 NRT call for proposals specifically refers to the 2015 National Academies report on team science effectiveness.[9] As such, it encourages STEM workforce development that enables students to acquire competencies in collaboration as well as in their respective fields of study. This acknowledgment of team science emphasizes its practice more than its study.

Other programs, such as NSF's GERMINATION[10] and EAGER (Early-Concept Grants for Exploratory Research)[11] programs have also provided funding to those who study science teams at a more foundational level. NSF's Innovations in Graduate Education Program[12] has supported several initiatives aimed at improving collaboration and cross-disciplinarity in student learning. The Food and Drug Administration (FDA) has also been practicing tenets of the science of team science. For example, to improve translational science, FDA's Center for Clinical Trial Innovation[13] promotes team science to improve collaborative effectiveness. Similarly, the Department of Energy (DoE) has formally acknowledged the importance of teamwork in research activities. More recently, NSF and DoE have partnered in their Correctness for Scientific Computing Systems program.[14] This program recognizes that such research requires close collaboration between researchers and, in service of cross-disciplinarity, notes that submitters develop teams comprising experts from different disciplines.

[8] More information about the Research Traineeship Program is available at https://new.nsf.gov/funding/initiatives/nrt

[9] More information about the August 16, 2024, call for proposals is available at https://new.nsf.gov/funding/opportunities/us-national-science-foundation-research-traineeship-program/nsf24-597/solicitation

[10] See https://www.nsf.gov/funding/opportunities/germination-germination-research-questions-addressing

[11] See https://new.nsf.gov/funding/early-career-researchers#early-concept-grants-for-exploratory-research-eager-c8f

[12] See https://new.nsf.gov/funding/initiatives/ige

[13] See https://www.fda.gov/about-fda/center-drug-evaluation-and-research-cder/cder-center-clinical-trial-innovation-c3ti

[14] See https://new.nsf.gov/funding/opportunities/cs2-correctness-scientific-computing-systems

A recent report on developing better scientific software notes the importance of cross-disciplinary teamwork in successful outcomes, specifically calling out a need to improve understanding on the variety of teams and individuals collaborating to develop scientific software (Heroux et al., 2023). In a section on cross-cutting themes, Heroux et al. (2023) note that social science research on teamwork can help "inform a variety of important challenges and opportunities in team-based scientific software development and use [...] Improving communication and interactions within and across teams can account for specific challenges in scientific software environments" (p. 17). The report goes on to discuss the importance of team interaction and managing conflict and communication across teams and multiteam systems (Heroux et al., 2023).

Ongoing Challenges and the Evolution of the Scientific Landscape

The aforementioned progress is not universal, and several long-standing and emerging challenges continue to hinder the success of science teams. One of the more difficult challenges, funding for the scientific study of science teams, has not been addressed. While sponsors fund science teams to conduct research and fund research on the science of teams more generally—understanding team dynamics in organizations and the military, for example—there is a significant lack of funding for the science of team science research (i.e., the scholarly examination of teamwork in science teams). This is problematic in that it contributes to the growing gap between theory, evidence, and practice in team science. Conducting research on teams is inherently challenging for several reasons, including the complexity of capturing dynamic, multilevel interactions; the need for longitudinal data to understand team evolution; and the difficulty of isolating variables in a team setting (Delice et al., 2019; Kozlowski, 2015; Shuffler & Cronin, 2019). Logistical challenges also arise, such as finding times when all team members are available and recruiting the entire team to participate in a study. Furthermore, scientists are often reluctant to participate, with possible reasons including their busy schedules, their multiple team memberships, and their involvement in both research activities and other activities relevant to their jobs. In addition, they might be skeptical of social science methodologies, such as qualitative methods and survey research, questioning their relevance or validity (Ledford, 2015). Because of these challenges and the lack of funding to address them, there is an unfortunate scarcity of mid- to large-scale research on science teams. Hence, as will be apparent throughout the present report, much of the research on team science comes from studies that do not focus exclusively on science teams and/or that are qualitative in nature.

An additional remaining challenge is the lack of systematic training of team science competencies. Team science members receive training in their discipline during the time they complete their terminal degrees. Often, however, they do not receive formal training on how to collaborate or share leadership roles with others on a team. As such, while scientists have acquired competencies relevant to their scientific tasks, too often they can fall short on competencies needed to work as a team on those tasks. This can lead to problematic collaborations that hinder the effectiveness of science teams.

While work to develop and execute programs for training in team science competencies has been considerable since the 2015 report, these programs exhibit considerable differences in both the specific competencies they aim to cultivate and the formats they use. Training programs can range from brief 1-hour sessions to comprehensive semester-long courses, and from interactive workshops to informal lunch-time lectures. Furthermore, the evaluation methods for these programs' effectiveness are equally varied, relying on metrics such as connecting the attendance to training with the number of new grant applications funded or publications accepted by attendees; in other cases, no evaluation metrics are used at all. This lack of standardization results in inconclusive training outcomes, underscoring the need for a more cohesive and universally adopted approach to team science education.

COVID-19

The emergence of COVID-19 caused many changes in society, including lockdowns, social distancing, and working from home, all of which affected the way teams worked. The National Academies has released multiple reports on COVID-19 and its effects on education, transportation, community engagement, and other aspects of dealing with this major upheaval in society.[15]

From a team science perspective, arguably the largest impact during and following the pandemic has been in remote and hybrid workplace policies and the concomitant reliance on virtual communication tools to complete work (Karl et al., 2022; Woodruff et al., 2021; see also Rubinger et al., 2020, for a discussion regarding the changes to scientific research meetings and conferences). During the pandemic, work-from-home mandates brought to light associated work–life balance and accessibility gains that many employees now come to expect as part of evolving workplace benefits (Choudhury et al., 2022; Lake & Maidment, 2023). As the pandemic concluded, employers needed to balance the justification for bringing personnel back into the office with a heightened awareness of the benefits of working from home.

[15] See https://nap.nationalacademies.org/search/?rpp=20&pp=4&ft=1&term=covid

As a compromise, employers established flexible hybrid work policies, but at the time of the present report, employers have been increasingly requiring employees to be present in the office—in some cases for the full work week—arguing that this arrangement is better for team cohesion, productivity, organizational culture, and innovation, among other things (Agovino, 2023; The White House, 2025). Employers may have internal data to draw upon to shape their evolving policies and practices, but there is limited scientific literature examining how work from the office, work from home, and hybrid work affect team performance and desired outcomes.

One study from 2024 analyzed the innovation activity of over 48,000 information technology professionals at an India-based firm, nearly all of whom had a minimum of a college degree in engineering (Gibbs et al., 2024). The study tracked a quantifiable internal innovation metric pre-pandemic (work from office), mid-pandemic (work from home), and post-pandemic (hybrid work). They found that while the quantity of submitted ideas did not change in transitioning from working at the office to at home, the average *quality* of submitted ideas declined (Gibbs et al., 2024).

In a related study, the authors found that productivity per hour decreased as well because of difficulties performing some work tasks in a virtual environment (Gibbs et al., 2023). As hybrid work in the post-pandemic era began, the *quantity* of submitted ideas decreased[16] (Gibbs et al., 2024). The authors posit that these declines are, at least partially, a result of less spontaneous interactions that naturally occur in the office, contrasted against work from home and hybrid work, which require some level of coordination, thus limiting the ability to have "productive accidents" (Gibbs et al., 2023). This study suggests that innovation suffers when engineers, in this case, are not in the office at the same time. However, the authors make clear that the reduced innovation output needs to be balanced against employee productivity, satisfaction, and environmental implications (Gibbs et al., 2023). In addition, when properly supported, flexible and remote work options tend to better align with ergonomics and wellness needs (Beckel & Fisher, 2022), key considerations for promoting effective team science.

A McKinsey Global Survey of executives describes how COVID-19 had changed the digital landscape of companies:

> In just a few months' time, the COVID-19 crisis has brought about years of change in the way companies in all sectors and regions do business. According to a new McKinsey Global Survey of executives, their companies have accelerated the digitization of their customer and supply-chain

[16] This decrease in idea quantity was greater for females than for males, revealing a gender asymmetry with potential consequences for performance biases and career advancement.

> interactions and of their internal operations by three to four years. And the share of digital or digitally enabled products in their portfolios has accelerated by a shocking seven years. Nearly all respondents say that their companies have stood up at least temporary solutions to meet many of the new demands on them, and much more quickly than they had thought possible before the crisis. What's more, respondents expect most of these changes to be long lasting and are already making the kinds of investments that all but ensure they will stick. In fact, when we asked executives about the impact of the crisis on a range of measures, they say that funding for digital initiatives has increased more than anything else—more than increases in costs, the number of people in technology roles, and the number of customers. (O'Toole et al., 2020, p. 2)

The acceptance of digital tools included using video conferencing for work, virtual national conferences, and social interaction with family and friends. During the pandemic, lockdown and continued social isolation also affected the way teams pursued science and how teams and research groups interacted. After lockdowns ended, a new work style was ushered in with "hybrid" rising in prevalence (Handke et al., 2024). In fact, since the COVID-19 pandemic, the adoption and integration of hybrid and virtual collaboration software have increased significantly across science teams (Kilcullen et al., 2021; Lematta et al., 2021; Miller, 2020; Paunov & Planes-Satorra, 2021). These tools offer various functions that enhance team communication, such as global video conferencing, text-to-speech capabilities, and large language models for summarizing meeting notes.

Technology

Generative AI tools, in particular, which were not widely available until after the 2015 report, could help advance scientific collaboration by assisting in some of the tasks that may be precursors to scientific progress, such as drafting reports and generating basic data analysis code to assist individuals and teams. In this sense, generative AI applications or agents may be viewed eventually as valuable tools or teammates in team science (National Academies of Sciences, Engineering, and Medicine, 2021). However, the use of these tools raises several concerns, including potential biases or confabulations in AI-generated content that still require human oversight (Bryson et al., 2017) and ethical implications of AI-authored or AI-assisted publications (Schlagwein & Willcocks, 2023).

The 2015 report recommended using collaboration software (National Research Council, 2015). Although studies address technology use in virtual and hybrid teams, including hypothesized factors such as knowledge, skills, and attitudes that affect virtual teams and their technology use (Gibson et al., 2022; Kilcullen et al., 2021; Ofosu-Ampong & Acheampong, 2022;

Schulze & Krumm, 2017), it remains unclear how—or whether—the collaborative functions of these tools truly facilitate effectiveness in science teams. An additional research issue is whether these new capabilities are being implemented more broadly to improve aspects such as adherence to universal design principles in science teams, and, if so, whether they have produced the desired result.

In addition to possible beneficial outcomes of technology use, many collaboration challenges can result. To mitigate or reverse any potential negative effects of a team working virtually, key factors such as team trust and conflict management require thoughtful leadership and communication that will likely be mediated by technology design and use in virtual and hybrid teams (Schulze & Krumm, 2017).

Geopolitical Tensions

Each of these areas underscores the significance of collaboration across geographic regions. However, with global collaborations, it is imperative to consider ever-changing geopolitical dynamics. Scientific progress and collaboration do not exist in a vacuum; they operate in the context of geopolitical forces that can both facilitate and potentially hinder collaboration among nations (Wagner & Cai, 2022). Considering the role of geopolitics in scientific progress and collaboration is not new. Ongoing research in Antarctica enabled by the Antarctic Treaty, for example, and in space as illustrated by the Outer Space Treaty and International Space Station, are examples of geopolitical challenges overcome for the advancement of science (Secretariat of the Antarctic Treaty, n.d.; United Nations Office for Outer Space Affairs, n.d.).

Nevertheless, many challenges persist. For instance, scientific collaborations between China and the United States began to decline in 2019, when political tensions around science, technology, and innovation arose, with the United States claiming that China was violating intellectual property norms (Wagner & Cai, 2022). Fostering sustained and productive international scientific collaborations will require continually addressing and navigating geopolitical complexities.

An increasingly important aspect of this geopolitical landscape is *research security*, which refers to protecting the integrity, confidentiality, and security of research activities, particularly those including human subjects, in a world where intellectual property theft, cyber threats, and the misuse of scientific knowledge are growing concerns (Office of the Director of National Intelligence, n.d.). As geopolitical tensions rise, particularly between major global powers, and as global scientific collaboration becomes more complex, safeguarding research from these threats is paramount (e.g., Gibney, 2024). National Security Presidential Memorandum-33 highlights the importance of safeguarding federally funded research and development for ensuring U.S. national security and outlines specific research security requirements that all institutions receiving more than $50 million in federal research and development funding are required to implement (The White House, 2021). This can include implementing robust cybersecurity measures; providing research security training; and ensuring compliance with international regulations related to export control and foreign research travel, as well as managing the risks associated with cross-border collaborations, especially in high-stakes research areas.

Geopolitical tensions can lead to restrictive policies on traveling to conferences, establishing collaborations, recruiting graduate students, buying and sharing technology, and data privacy and security. For example, the Florida "Countries of Concern" law for higher education, signed in 2023, imposes restrictions on Florida's public universities' interactions with China, Cuba, Venezuela, Russia, Iran, Syria, and North Korea (Florida Senate, 2022). The law prohibits Florida colleges from receiving grants, forming partnerships, or conducting research collaborations with institutions based in or controlled by these countries (State University System of Florida Board of Governors, 2023). Although the legislation was aimed to prevent potential risks related to national security, including intellectual property theft and influence by foreign governments, it also led Florida public institutions to close international programs in China and to end partnerships and reduce graduate student recruitment efforts with these nations (e.g., Knox, 2024; see also Rivero, 2024; Voice of America News, 2024). As a consequence of this law, faculty, researchers, staff, and student assistants at these institutions have to go through additional approval processes to travel to conferences and research events held in these countries.

In conclusion, significant growth and attention in the field of team science has led to numerous successes in the application of team science principles and recommendations from the previous report (National Research Council, 2015). Nonetheless, there is still room for improvement as the applications of some of the recommendations have not been fully realized and new challenges have arisen over the last decade.

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3

Best Practices

This chapter addresses the questions outlined in the statement of task (see Box 1-1 in Chapter 1) concerning best practices for supporting team science, including those related to training and education, virtual collaboration, and incorporating nonscientist team members. Drawing from the literature, committee expertise, and expert presentations, the chapter summarizes the current understanding of which best practices to implement within a science team, how to implement them, and when they could be applied to enhance team effectiveness. The committee defines *best practice* as an activity or strategy that can enable a science team to collaborate effectively to achieve its goals; it is synonymous with the term *team development intervention* in the broader literature on team effectiveness (Shuffler et al., 2018).

The chapter begins with an overview of best practices related to education, training, and professional development opportunities to support team science. These opportunities form the foundation of a healthy team science ecosystem and prepare individuals to collaborate effectively as members of science teams. The chapter also articulates a series of best practices that can be implemented throughout the life cycle of a science team to potentially improve team effectiveness. Table 3-2 at the end of the chapter outlines suggested best practices discussed throughout.

EDUCATION, TRAINING, AND PROFESSIONAL DEVELOPMENT

As noted in Chapter 1, the success of a science team depends on the technical expertise of its members, known as taskwork competencies, and on their ability to collaborate effectively, reflected in teamwork competencies.

Thus, *team science competencies*, or the knowledge, skills, and abilities required for team science success, extend beyond scientific expertise to include competence in communication, coordination, conflict resolution, and the ability to work across disciplinary and organizational boundaries. By developing both taskwork and teamwork competencies, members of science teams can better navigate the complex dynamics of scientific collaboration.

Teamwork and taskwork competencies can be either context-specific or transferable (Cannon-Bowers et al., 1995; Cannon-Bowers & Salas, 1998). *Context-driven competencies* are necessary for a specific team working on a specific scientific task. These competencies are particularly relevant to teams with consistent membership that perform similar tasks over time. *Team-contingent competencies* are those specific to a particular team, but the competencies are more generic in that they can be applied across different scientific tasks. These competencies are particularly relevant to science teams that work together regularly but handle a variety of projects. *Task-contingent competencies* are specific to a type of task but can be applied across different teams, and they are valuable when tackling a scientific problem that may involve different teams. Finally, *transportable competencies* are both team and task generic in that they can be applied across a range of tasks and teams. These general competencies are crucial for effective collaboration in any scientific context. Therefore, interdisciplinary graduate programs and professional development for team science often emphasize them (Fiore et al., 2019). While many existing programs and professional development opportunities focus on those earlier in their careers, including students, it is important to note that seasoned faculty could also benefit from participating in training opportunities. Faculty have cited time demands, a lack of incentive, and a lack of career-stage-appropriate training as barriers to their participation in professional development activities (Brownell & Tanner, 2017; Vela et al., 2023).

Developing team science competencies, especially those transportable across tasks and teams, is essential for supporting the team science ecosystem. Building these equips individuals to contribute meaningfully, collaborate productively with others, and ultimately function as members of effective science teams, thereby driving the success of collaborative scientific endeavors.

Team science competencies are developed in various ways. Although many team science competencies are acquired through “on-the-job” learning, more structured efforts can cultivate these skills (see Fiore et al., 2019). In addition to the availability of online resources, such as those available through the International Network for the Science of Team Science[1]

[1] To learn more about the International Network for the Science of Team Science and view available resources, please visit https://www.inscits.org

and the University of California, Irvine's Team Scholarship Acceleration Laboratory,[2] these efforts include workshops ranging from a few hours to several days or longer, courses focused on interdisciplinary topics within academic curricula, or short courses offered to faculty. The *Enhancing the Effectiveness of Team Science* (National Research Council, 2015) report spurred the development of the training program TeamMAPPS, which was based on identified knowledge, skills, and activities integral to successful team science work (Bisbey et al., 2021b). In addition, some programs incorporate team science competencies into their mentoring initiatives. The sections that follow provide examples of programs designed to develop team science competencies.

Workshops

Workshops are organized, structured interventions designed to bring together individuals to engage in collaborative learning, skill development, and reflection over a few hours to a few days. Typically, workshops focus on specific learning objectives, such as fostering interdisciplinary understanding, enhancing competencies related to collaboration, and bringing together unique ideas to generate innovative and transdisciplinary frameworks. These objectives are accomplished through various interactive activities, such as discussion, practical exercises, and assessment. These activities can provide participants with a safe environment to explore different perspectives, practice their team science skills, and develop a greater epistemological awareness (Audi, 2010). Workshops can vary in both length and format, from multiday immersive programs to half-day informational sessions. This section continues by describing the results of several studies on the outcomes of science team training workshops.

One study, for example, explored how workshops can enable science and engineering doctoral students to develop a better understanding of the various perspectives held by experts from different disciplines (Gosselin et al., 2020). This study of dispositional and epistemological characteristics found that a 9-day workshop intervention exposed students to different ways of thinking. Gosselin et al. (2020) considered factors such as communicating different perspectives and valuing insights from others. Using retrospective pre- and post-module evaluation and data from questionnaires and group reflections, they assessed participants' behavioral and dispositional differences, finding that the workshop helped students increase awareness about their own values associated with science knowledge and how these values differ from those of others on their team. The authors suggest that

[2] To learn more about the Team Scholarship Acceleration Laboratory and access resources, please visit https://tsal.uci.edu

such workshops help students begin "their journey to understanding the importance of learning to navigate and negotiate dispositional distances and other forms of compositional diversity as part of collaborative processes" (Gosselin et al., 2020, p. 321). Although the assessments and interventions were proprietary in nature, these workshop formats could be followed with more open-source measures that examine similar competencies.

In support of ideation and knowledge integration, innovation labs are a type of workshop designed to support learning about others and developing new ideas for transdisciplinary research (Hawk et al., 2024). In one study, facilitators supported early career scholars in a creative problem-solving process and assessed participants on competencies such as collaboration readiness and interest in starting new research projects. This study also examined team formations and writing research grants, new publications, or both based on activities from the workshop. Compared with scientists who engaged in normal institute activities, Hawk et al. (2024) found little to no differences in attitudes toward collaboration or research productivity. However, they found increases in the intent to submit grant proposals among innovation lab participants. What is most useful about this approach is the attention to outcomes over a longer duration, with the researchers examining several factors over time, including collaboration readiness and collaboration network size at 12 months and 21 months postintervention, respectively (Hawk et al., 2024).

Another study examined learning and attitude change for faculty members who received seed funding awarded to support research idea development in interdisciplinary teams (Morgan et al., 2021). Attendees at this workshop were a mix of junior- and senior-level faculty in several disciplines, including social and life sciences, engineering, and humanities. The workshop, comprising two half-days, had several sessions targeting a set of team competencies meant to develop collaborative capabilities of team members. These ranged from team science knowledge, such as best practices, collaboration skills, including communication and interpersonal collaboration, and team regulation type concepts, such as goal setting and meeting coordination. Activities such as group discussion, quizzes, and templates for teamwork provided practice in these different competencies. To measure outcomes, the investigators used pre- and post-test change measures, along with subjective reactions to the variety of content in the workshop. In general, the participants' subjective reactions to the workshop sessions were that they were useful. Among participants who attended at least one of the workshop sessions, there was evidence of some attitude changes, including rating themselves as more ready to collaborate, as well as increases in behavioral trust. However, there were no changes in team-focused concepts around clarity of roles, goals, or processes (Morgan et al., 2021).

Courses

Courses can be leveraged to develop team science competencies over a longer time period. By balancing lecture- and activity-based learning, courses provide opportunities to understand concepts and ideas in theory and then give participants opportunities to apply these learned competencies in practical, real-world contexts. Assessing learned competencies in this format may include reflective writing, oral presentations, team projects, declarative knowledge exams, and practical application of skills.

One study of a course designed specifically to improve team science competencies such as mentoring and debriefing found some increases in leadership self-efficacy and improvements in various facets of collaboration (Tumilty et al., 2022; see also Appendix B). This study measured leadership self-efficacy using the Kane-Baltes Leadership self-efficacy test, which assesses a person's beliefs that they can perform successfully as a leader. The course, which used authentic learning activities, focused on interprofessional training for transdisciplinary teams, examining how to acquire specific (e.g., leadership training) and general collaborative competencies (e.g., grant writing, interactions with experts such as biostatisticians). Finally, the participants received formative feedback regarding their work on proposal writing and oral presentations, for example. This course emphasized team science competencies, including collaborative behaviors such as monitoring and reflection, perspective seeking, and inquiring about and probing research ideas. Also included were tools such as interactive team contracts, which showed benefits such as addressing issues in the team. Participants showed beneficial effects on communication, integrating certain practices into their writing, such as open communication styles, empathic practices, and collaborative workflows (Tumilty et al., 2022). Overall, the methods used here can provide an effective template for both developing team–science relevant courses and evaluating their effectiveness.

One group of investigators developed coursework for promoting interdisciplinary education, with an equal focus on faculty instructors and students (Corbacho et al., 2021). They examined teaching practices that could trigger academic motivation and how different teaching teams used a common strategy to create a collaborative interdisciplinary environment, leading to consistent student experiences. The investigators also examined what distinguishes interdisciplinary courses from traditional ones. Using tools such as the Student Course Experience Questionnaire (Ginns et al., 2007) and the eMpowerment, Usefulness, Success, Interest, and Caring Model of Academic Motivation (Jones, 2009), Corbacho et al. (2021) assessed how well students recognized key components of interdisciplinary teamwork. In the context of teaching, this study identified some challenges, including teachers feeling out of their comfort zones when applying team-building practices and creating open-ended problems.

In 1998, the National Science Foundation (NSF) created the Integrative Graduate Education and Research Traineeship (IGERT) program to both develop interdisciplinary competencies in students and support changes in scholarly culture at participating universities. Although NSF ended IGERT in 2013—NSF recently created the NSF Research Traineeship (NRT) program to similarly support interdisciplinary, evidence-based traineeships (National Science Foundation, 2024)—researchers have examined its effects and highlighted critical findings. For example, one report discussed the overall purpose of the program and summarized the formal and informal ways IGERT awardees developed interdisciplinary competence (Van Hartesveldt, 2016). Awardees of IGERT funding created new courses in a collaborative way to ensure that faculty with varied perspectives contributed to an interdisciplinary curriculum. From these courses, graduate students learned about other disciplines and each other as they engaged in research team projects.

One of the primary goals of these courses was to increase multidirectional communication skills, including communicating ideas effectively, especially with those from other disciplines. IGERT projects included informal mechanisms such as boot camps or summer sessions that provided more experiential forms of learning, as well as an opportunity for focused learning and interaction. More broadly, IGERT included cross-mentoring, where faculty guided students from different disciplines. In general, IGERT outcomes promoted students' attitudes toward learning and cross-disciplinary research (Van Hartesveldt, 2016).

The same report described findings suggesting that IGERT students tended to produce dissertations that incorporated more disciplines (Van Hartesveldt, 2016). IGERT students were also more active in conducting interdisciplinary research and creating interdisciplinary programs. Additionally, the report highlighted longer-term analyses in which graduates of IGERT programs said they were still drawing on their experience and competencies gained while in their graduate program (Van Hartesveldt, 2016).

Mentoring Programs

Mentoring programs are a great resource for developing team science competencies in a less formal environment over prolonged periods of time. *Mentoring programs* are structural initiatives that assign experts—mentors—to support their protégés' development in specific activities that align with the mentoring program's purpose.[3] Mentoring programs use a

[3] While informal mentor–protégés relations that develop more organically exist, they are not the focus of this section.

variety of frameworks (e.g., Montgomery & Page, 2018), such as a traditional hierarchical structure consisting of one mentor and one protégé, as well as nondyadic structures, including one mentor and one team, or team members mentoring each other. In the context of team science, these programs aim to enhance both teamwork (e.g., improving collaborative competencies and cross-disciplinary understanding) and taskwork (e.g., technical and research competencies) through such activities as direct mentoring interactions, experiential training, and collaborative exercises (National Academies of Sciences, Engineering, and Medicine, 2019; Rodríguez et al., 2021).

The federal government has been active in supporting mentoring programs for graduate students and early career professionals. The National Cancer Institute programs sometimes focus on developing both teamwork and taskwork by promoting an appreciation of different perspectives on scientific issues. These provide multiple mentors spanning a range of competencies that need to be developed based upon mentor needs. For example, the Transdisciplinary Research on Energetics and Cancer Centers initiative (Gehlert et al., 2015; Vogel et al., 2012) has postdoctoral scholars identify and select mentors that span disciplines with the goal of enhancing inter- and intrapersonal competencies. The Academic Learning Health System Scholars Program also assigns multiple mentors, including a primary mentor, co-mentor, Translational Research Training Program core faculty mentor, peer mentor, and health system mentor (Woodside et al., 2021). Along with this set of mentors, the postdoctoral scholars also participate in collaborative forms of training, including transdisciplinary research courses, journal clubs, and workshops to develop skills in collaborative writing. Even if not specifically identified as such, a primary objective of these programs is to improve teamwork and taskwork, as they are designed to expose trainees to multiple disciplinary perspectives, to increase research competencies, and to enhance attitudes about collaboration. The overall goal is greater scholarly productivity based on becoming a more team-oriented scientist.

The National Institutes of Health (NIH) Building Interdisciplinary Research Careers in Women's Health program also includes a mentoring component.[4] This program is designed for junior faculty interested in advancing cross-disciplinary research in women's health; it provides multiple perspectives on a range of scientific and career issues. Nagel et al. (2013) evaluated this program using success indicators such as improved idea generation based on more grant submissions in women's health. This program

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[4] More information about the BIRCWH program is available at https://www.mayo.edu/research/centers-programs/womens-health-research-center/education/building-interdisciplinary-research-careers-womens-health-program

identified a set of recommendations or best practices for ensuring success in team-based mentoring, including development of a written contract or agreement between participants to manage mentoring expectations (Guise et al., 2012) and clearly articulating roles for the mentoring team, such that some focus on career issues while others focus on scientific content (see also Guise et al., 2017).

More recently, the NIH Clinical and Translational Science Awards (CTSA) Program has developed an approach that focuses on teams of trainees. CTSA combines didactic and experiential training in team science that includes cross-disciplinary mentoring (McCormack & Strekalova, 2021). Team composition is also a focus; mentors are assigned two students pursuing PhDs or dual degrees (e.g., MD-PhD). In addition, these mentee teams need to be pursuing their doctoral degree in different disciplines and in different colleges. Thus far, there is evidence of an increase in collaborative activities of both the CTSA team trainees and mentors (McCormack & Strekalova, 2021). Some attitudinal changes are also evident: two-thirds of mentees noted that they plan to continue collaborations after training and to continue using the support tools, such as collaboration plans and author agreements, to which they were introduced in the CTSA program (McCormack & Strekalova, 2021).

In a recent review of team mentoring approaches, whereby mentees are assigned multiple mentors with the goal of providing a variety of disciplinary and professional perspectives, one report described how team mentoring can improve transdisciplinary science (Shah & Fiore, 2022). The authors noted that team mentors support professional development by providing career guidance and direction and improving exposure to critical people; these help mentees gain insights about political culture, organizational culture, or both. Furthermore, the mentoring team acts as advocates on behalf of the mentees and can help identify opportunities for research and critical resources needed for early career success (Shah & Fiore, 2022).

The same review provided a set of guidelines for team mentoring to help identify targets for collaborative competencies, such as active listening (Shah & Fiore, 2022). For example, mentors can demonstrate active listening with their team by asking follow-up questions when discussing complicated issues. As a complement, mentees can practice active listening by discussing research with those from other disciplines. Shah & Fiore (2022) pointed out that mentors can enhance competencies in assertive communication by creating a safe environment for arguing around research topics, where mentees can readily address their opinions and ideas in task-focused ways, ensuring that all ideas are being considered.

Shah & Fiore (2022) discussed guidelines for team mentoring in cultivating interpersonal competencies, including understanding coordination. For example, mentors could create artifacts delineating roles and goals on the team and expectations for different mentors. In addition, mentees can provide feedback to mentors when they are unclear about roles or goals while also learning how to safely ask for assistance as needed. This coordination and delineation of goals becomes particularly important for multiteam systems, where teams have to balance both local and shared goals (Shuffler et al., 2015).

Another important interpersonal competency is cultivating an appreciation of varied perspectives (Shah & Fiore, 2022). For example, mentors can model respect for theories, methods, or both that come from different fields during team meetings. Mentees can learn how to better attend to, and maintain awareness of, any experience of positive or negative commentary about other disciplines, such as disdain for a particular field, and be comfortable discussing why such attitudes are problematic.

BEST PRACTICES FOR SUPPORTING SCIENCE TEAMS

The past century of research on team effectiveness across industries has demonstrated that key *teamwork processes*—such as coordination, information-sharing, and conflict management—and *emergent psychological states*—such as cohesion, shared mental models, and transactive memory systems—are linked closely to achieving team objectives (Bell et al., 2018; Kozlowski & Chao, 2018; Mathieu et al., 2018). Moreover, research on team effectiveness has identified numerous best practices and team development interventions that teams and team leaders can deploy to support critical teamwork processes, emergent states, and team goal accomplishment. In this section, the committee articulates how to apply these best practices in the context of team science.

The committee framed its discussion of team science best practices according to the four stages of transdisciplinary research (Hall et al., 2012). The first stage, *development,* involves establishing a shared understanding of a scientific problem space and group mission. During the second stage, *conceptualization*, the team develops research questions, conceptual frameworks, and research designs to integrate and expand approaches from multiple disciplines. In the third stage, *implementation,* the team focuses on initiating, executing, and refining the planned research. Finally, *translation* involves applying research findings to develop innovative solutions for real-world problems.

Although these four phases are conceptualized as sequential, they are highly interconnected and are nonlinear for many teams (Hall et al., 2012). For instance, a team may cycle between the conceptualization and implementation phases many times before progressing to translation. This aligns with the broader teams literature, which emphasizes that teams cycle repeatedly through *transition phases*, marked by activities such as planning and mission analysis, and *action phases* involving tasks such as coordination and back-up behavior (Marks et al., 2001). In addition, not all teams will engage in all four phases, particularly if transdisciplinarity is not a primary research goal. However, the overall organization of this section broadly mirrors the evolving and dynamic nature of science teams and how a team's challenges, opportunities, and needs will shift over time, depending on the goals of the science. Basic science teams, for example, still engage in these early phases.

The remainder of this chapter outlines best practices for supporting a science team corresponding to the four phases of transdisciplinary research. Some best practices, such as those pertaining to leadership or virtual collaboration, can transcend all four team stages and are thus afforded their own sections. Understanding the phase within which a science team is situated and leveraging corresponding best practices during that phase improves the likelihood that the team will produce its desired outcomes.

Phase I: Development

In the development phase, a group of potential collaborators comes together to define the scientific or societal problem of interest, including its complexities and boundaries (Hall et al., 2012). Collaborators might be selected based on their relevant disciplines and perspectives to address the problem comprehensively. One framework, for example, identified several teamwork processes that are likely to be essential to team success during the development phase. The authors suggested that, during development, science teams can work to generate a shared mission and goal and ensure all members are aligned and motivated to pursue a common purpose. Another important process during the development phase is fostering critical awareness, where team members gain a broad understanding of the problem space and the different perspectives and expertise each team member brings (Hall et al., 2012). For example, as discussed in Chapter 1, community members and/or nonscientist team members may be instrumental in defining the problem space.

The authors also argue that the development phase can involve externalizing group cognition, which involves making explicit the team's collective knowledge and thought processes (see Fiore & Schooler, 2004). Externalizing cognition plays a functional role in science teams in that it supports discussion and elaboration and helps teams identify points of agreement and confusion (Fiore & Wiltshire, 2016). *Psychological safety*, defined as the belief that a group is safe to engage in interpersonal risk-taking, is essential during the development phase, given that psychological safety encourages open communication, risk-taking, and the sharing of ideas that are critical for generating new knowledge as a science team

(Edmondson & Lei, 2014). It is important because it helps teammates feel safe to ask questions, challenge ideas, and share perspectives without facing consequence or judgments. Together, these processes lay the foundation for effective collaboration and set the stage for successful research or problem-solving efforts. The following best practices during the development phase can help achieve these developmental processes and emergent states.

Best Practice: Team Assembly

Being intentional, strategic, and discerning when composing a team is a critical step toward effective team science, with the team's purpose, needs, and tasks front and center. Team assembly includes (a) team task analysis, or thinking through the demands of the team; (b) team composition, or understanding the individual characteristics needed within the team; and (c) team member recruitment, or identifying and recruiting potential teammates.

Conduct a Team Task Analysis. A *team task analysis* is defined as "the process by which the major work behaviors and associated [knowledge, skills, and abilities] that are required for successful job or task performance are identified" (Arthur et al., 2005, p. 654). This analysis can be undertaken during and immediately after team assembly. Team task analysis involves articulating the key tasks the team will accomplish and determining how many individuals will be needed to perform those tasks; the complexity and interdependence of tasks; their frequency; and the specific knowledge, skills, and abilities required to complete them (Shuffler et al., 2018). A team task analysis can reveal which academic disciplines or areas of expertise are essential to achieve project goals. It can also help teams take a broader view of how tasks, especially those that are cross-disciplinary, may or may not align, potentially pointing to the need to prioritize generalist team members who can facilitate communication and collaboration across boundaries (Bammer, 2013). Multiteam systems face even greater challenges in aligning team goals, managing cultural differences, and coordinating tasks; identifying individuals who can facilitate this communication and collaboration can help with information exchange, trust-building, alignment of objectives, and maintaining system-wide cohesion (Carter et al., 2019; Kotarba et al., 2023; Zaccaro et al., 2020).

Following a team task analysis, the context, problem of interest, goals, timeline, funding, and other factors determine the appropriate size of a team (Hall et al., 2018). It is important that team size be commensurate with both the quantity and quality of tasks identified as necessary to solve a problem or test a hypothesis. Bibliometric analyses have found that larger teams tend to focus on more rapid development, adding incremental advances, whereas smaller teams produce more innovative outcomes that take time to make an impact (Wu et al., 2019). Thus, team sizes will vary depending on the scientific objectives of the research. It is worth noting that larger teams have higher coordination costs due to the need to align more individuals, institutions, time zones, and so on (Berntzen et al., 2021; Faraj & Sproull, 2000; Forscher et al., 2023; Pendharkar & Rodger, 2009). Stronger efforts may also need to be made to ensure larger teams with weaker ties do not splinter into siloed objectives, tasks, and outcomes (Jeske & Olson, 2024).

Decisions around team size could also benefit from considering team freshness, or how incorporating new members and perspectives might impact an existing team's performance. In an analysis based on article citations as a proxy for impact, for example, smaller teams were found to be more negatively affected when new members were added (Liu et al., 2022), potentially resulting from a more concentrated effect of being unfamiliar with one another's work-related experiences, skills, styles, and values. The effect of a new member on team performance has been shown to differ depending on how similar the new member is to existing members in relational and task-related characteristics (Liu et al., 2023b). New members that differ from existing members in characteristics related to accomplishing work tasks are associated in positive reactions from existing team members, while those who differ in aspects such as trait likability are associated with negative reactions (Liu et al., 2023b). These findings are at odds with traditional research on teams that show how turnover can improve innovation (Levine et al., 2003) but may depend on how experts are coordinated (Newton et al., 2019). Such findings illustrate why more research is needed on science teams to identify what is extendable or not from the science of teams.

Consider Team Composition. The team task analysis and identification of knowledge, skills, and abilities feed directly into *team composition*, or selecting individuals to form a team. Scholars have often emphasized that team selection decisions ought to consider both taskwork and teamwork competencies. For example, there is increasing support for selecting team members who demonstrate collaborative attitudes and behaviors, rather than those who exhibit more individualistic styles of thinking and working (Kilcullen et al., 2023). This concept, known as *team orientation,* encompasses both an individual's preference for working in a team versus working alone, for example, and their belief in teamwork as an effective means to get work done and accomplish goals. Individuals with a high level of team orientation tend to contribute positively to team functioning by promoting higher levels of cooperation and creating an environment where the team collectively believes in its ability to succeed (Kilcullen et al., 2023). Trust and cohesion, emergent psychological states that have been shown to be critical for team effectiveness, are also enhanced when team members are oriented toward teamwork (Kilcullen et al., 2023). The literature on team science recognizes the importance of team orientation, with scholars emphasizing that team-oriented individuals are more likely to engage in the collaborative processes necessary for scientific innovation (Fiore et al., 2019; National Research Council, 2015). In addition, team orientation is a key component of collaboration readiness (Hall et al., 2008).

Science teams might also prioritize including potential team members who exhibit a *transdisciplinary orientation*, a characteristic that develops over the course of an individual's career, reflecting their values, attitudes, and beliefs as well as the behaviors necessary for effective cross-disciplinary collaboration (Misra et al., 2015). Going beyond merely appreciating or valuing interdisciplinary work, transdisciplinary orientation encompasses the cultivation of the specific competencies required for transdisciplinary work and a demonstrated history of engaging in such collaborations. However, as with valuing interdisciplinary collaboration, transdisciplinary orientation is underresearched.

Many other individual characteristics—such as agreeableness, conscientiousness, openness to experience, collectivism, and preference for teamwork—have been linked with team effectiveness in other contexts (e.g., Barrick et al., 1998; Bell, 2007). Moreover, science teams are likely to reap innovation and creativity benefits when team members with different identities and lived experiences are supported appropriately (Smith-Doerr et al., 2017). For example, research has shown that variety across demographic factors improves team performance and scientific impact (Hall et al., 2018). These teams can also be more effective at problem-solving, decision-making, and innovating, including when adopting participatory approaches that invite nonscientist members to inform research need, relevancy, feasibility, and outcomes (Tebes & Thai, 2018; Wallerstein et al., 2019). For example, gender has been the focus of statistical analysis using quantitative methods for studying patterns in scientific outputs such as publications and grants since the 2015 report (Aksnes et al., 2019; Fox et al., 2018; Huang et al., 2020; Jadidi et al., 2018; Kwiek & Roszka, 2021, 2022; Liu et al., 2023a; Nielsen et al., 2018; Smith-Doerr et al., 2017). Yang et al. (2022) found that science teams that have both men and women produce more novel and highly cited papers than single-gender teams. This advantage increases with greater gender balance and on average is consistent across team sizes and subfields and does not depend on the team leader's gender; it applies to all science fields over the past 20 years (Yang et al., 2022).

Research in team science has also focused on examining aspects of heterogeneity beyond gender and discipline to include nationality and how that influences the collaboration process and research output of teams. Specht & Crowston (2022) examined scientific working groups that varied in terms of gender, discipline, and nationality and how team composition influenced collaboration and outcomes. They found that key aspects of team composition had positive effects on the interdisciplinarity of the collaboration process, defined as the range of the disciplines of the journals the teams published in and those they cited in their publications. Specifically, Specht & Crowston (2022) found that teams with more women had greater cited discipline variety and teams with more discipline variety had greater cited discipline and publication records. In a related study, Smith-Doerr et al. (2017) found a positive correlation between the participation of more women in disciplines traditionally dominated by men and expanded scientific research agendas. However, there was a negative relationship between publication variety and the presence of different nationalities on the team (Specht & Crowston, 2022). Outcomes were measured by the number of publications and the impact of the group's work by computing the median number of citations. This study also assessed team satisfaction and perceived team effectiveness and found that individual level of satisfaction was positively related to the number of publications the teams produced and with the proportion of women on the team. Moreover, the investigators found a negative relationship between country and work practices—as measured by the level of variety of articles sourced, for example—on personal satisfaction and perceived effectiveness of the team (Specht & Crowston, 2022).

However, increasing differences across demographic factors on teams has been described as a "double-edged sword" because of its potential for both positive and negative effects (Milliken & Martins, 1996, p. 403; Smith-Doer et al., 2017; Verwijs & Russo, 2024). Empirical evidence indicates the effect of heterogeneity on team outcomes is complex and may vary by how it is measured (Horwitz & Horwitz, 2007). Understanding these nuances is essential for leveraging individual differences to improve team performance. Several theories can help explain the potential for positive and negative effects associated with team variability. Information processing theory suggests that heterogeneous teams benefit from a wider range of information, knowledge, and perspectives, which can enhance decision-making and problem-solving (van Knippenberg & Schippers, 2007; Williams & O'Reilly, 1998). One area of organizational science research introduced the term *faultlines*, which are ways in which teams may split into subgroups based on one or more attributes (Lau & Murnighan, 1998). Research on faultlines has shown they are related positively to conflict and negatively to information elaboration, team performance, and team satisfaction (Thatcher et al., 2024). Social categorization theory posits individuals can view dissimilar team members as "out-group" members, potentially causing communication difficulties, conflict, faultlines, and reduced cohesion (Verwijs & Russo, 2024; Williams & O'Reilly, 1998). Several meta-analyses have grouped demographic variables into those that are highly job-related or less job-related, as well as task-oriented (related to completing tasks) or relation-oriented (related to building relationships; e.g., Joshi & Roh, 2009; Webber & Donahue, 2001). One meta-analysis (Bell et al., 2011) examined variability and team performance relationship by focusing on specific variables rather than grouping variables, as was done in past meta-analyses. Bell et al. (2011) found that having team members who represented the different functional areas in an organization, such as marketing and finance, was consistently related positively to team performance, while demographic variables such as education-level, team tenure, and organizational tenure consistently demonstrated no relationship between variability and team performance.

To determine the extent to which potential team members possess the requisite knowledge, skills, and abilities for a specific science team, scholars have suggested conducting detailed interviews that collect information on disciplinary expertise, as well as values and competencies such as interactional expertise, behaviors, and team orientation (Knott et al., 2022). The team science literature offers guiding questions to gauge individual and team readiness—such as how much the team trusts one another to make individual compromises in favor of an integrated team approach, how available an individual is to collaborate, and how feasible it will be to work across the constraints of different participants and institutions (e.g., O'Rourke et al., 2019, p. 32).

Scientifically derived and empirically tested team readiness instruments represent another means by which a team can make decisions about its members. Both the *Motivation Assessment for Team Readiness, Integration, and Collaboration* instrument (Mallinson et al., 2016) and the *Collaboration Success Wizard* (Bietz et al., 2012) use survey responses to assess how individual motivations and orientations may coalesce into team-level opportunities and vulnerabilities. Another example, the Interdisciplinary Perspectives Index, measures the degree to which individuals value interdisciplinary work and captures their attitudes and emotional responses toward the significance of this work (Misra et al., 2009).

Recruit Team Members. The process of assembling a science team is often complex and informal. First, there is the challenge of finding the right individuals. Although it might be clear what expertise or knowledge is needed for the team, locating individuals who possess those skills and are willing to participate in the team can be difficult. This process is often driven by informal networking, where researchers rely on personal contacts, recommendations from other scientists, recommendations from nonscientist partners, or discussions at academic conferences to identify potential collaborators (Lungeanu et al., 2014, 2018; Zajdela et al., 2022). Such approaches, while often effective, are also unpredictable and may leave team leaders with limited options if they lack the necessary connections within their fields or across disciplines.

Indeed, recruiting science team members is unlike team assembly in many industries, where team formation can follow a traditional, structured process—for example, a leader identifies a clear goal, posts job ads, interviews candidates, and selects the best fits. Instead, researchers may initiate collaborations based on mutual interests, long-standing professional relationships, or chance encounters at conferences or workshops. Many science teams are formed first without a fully developed goal or project in mind, and the task itself may only take shape once the team members are assembled (Wang & Hicks, 2015). This informal process is further complicated by the fact that many scientific collaborations start with a vague idea or broad topic of interest, and only after initial discussions do the collaborators flesh out specific goals and methodologies. As a result, team members are often chosen not because they fit neatly into a predefined role, but because they bring a unique perspective or area of expertise that helps shape the project as it evolves. In these cases, the goals and tasks are developed alongside the team composition, rather than preceding it, and team composition can shift or expand as the project becomes clearer.

Moreover, even when scientists have a well-defined task or research goal in mind, assembling a team with the right mix of competencies and expertise is not easy. When team members lack extensive networks or are looking to expand into unfamiliar disciplines, technological resources, such as third-party scientific expertise databases, can facilitate collaborator searches (National Research Council, 2015). Artificial intelligence (AI) models can also be trained to analyze research networks and identify relevant experts (Sourati & Evans, 2023; Xu, 2025). It is important to note, however, that several AI systems have perpetuated biases in hiring decisions, including in aspects such as race and sex (Dastin, 2018; Lee et al., 2019). Nonetheless, technological resources are less helpful for identifying individuals who possess the necessary combinations of teamwork and taskwork skills.

An additional challenge is convincing identified individuals to join a team. This is no small task in the world of science, where researchers are often stretched thin across multiple projects, grants, teaching responsibilities, and institutional roles. Even if a scientist is interested in the proposed project, they might not have the time to take on additional work. Moreover, team members need to be personally motivated to participate, whether because they find the research question compelling, see potential for career advancement, or value the opportunity to collaborate with particular individuals (Adler & Chen, 2011; Bennett & Gadlin, 2012). Without sufficient intrinsic or extrinsic motivations, it can be difficult to persuade highly capable scientists and other potential team members to commit their time and energy to a new collaboration.

Convincing potential collaborators to join a science team often involves articulating a compelling vision for the project. Team leaders or initiators may need to communicate the scientific value of the project as well as how participation will benefit each team member. Whether it is through the promise of publications, opportunities for professional networking, or the ability to contribute to cutting-edge research, individuals need to feel that their involvement is worthwhile (Bennett & Gadlin, 2012). In addition, clear expectations around roles, time commitments, and contributions are crucial to ensuring that potential team members feel confident about joining. Without this, even highly motivated individuals may be hesitant to sign on. Thus, the process of science team assembly is not only about finding and recruiting the right people, but also about creating the right environment, one where potential team members see value in the project, feel motivated to contribute, and have clarity about what their roles will entail (Bennett & Gadlin, 2012).

Best Practice: Team Onboarding and Building

After team assembly, onboarding team members in ways that increase both work-related and personal familiarity is important for team effectiveness (Tannenbaum et al., 2023). Onboarding can include sending welcome letters with essential information, such as team member biographies and key points of contact, and facilitated discussions to promote mutual understanding around a project's central components and highlight individuals' strengths (e.g., the Toolbox Dialogue Initiative; see Bennett et al., 2014; Hubbs et al., 2020). As discussed in the next phase, collaborative agreements (i.e., team charters) can establish a shared set of expectations and synchronize team members into a cohesive vision. Team membership is often not static over time, meaning onboarding activities may need to occur during any phase in which new members are added to build and maintain shared mental models of the collaborative work. For example, teams could appoint an onboarding buddy to help a new member integrate into a team (Tannenbaum et al., 2023). Onboarding strategies can focus on providing sensitivity training, co-creating a team culture that supports work–life balance, implementing universal design principles, and fostering mentor–protégé relationships within the team (Arslan et al., 2025; Behar-Horenstein & Prikhidko, 2017; Mosca & Merkle, 2024; Wellemeyer & Williams, 2019).

Onboarding strategies can incorporate team-building as a proven means of enhancing interpersonal relationships (Klein et al., 2009). Interpersonal relationships help to strengthen social ties on a science team, which can help both launch and sustain collaborations over the long term (Smith et al., 2016). By strengthening team bonds, team-building can foster team cohesion and trust and a team climate that promotes perseverance and constructive conflict resolution (National Research Council, 2015). A recent case study highlighted the positive connection between interpersonal relationships and science team productivity (Love et al., 2021).

Research suggests that to be most effective, team-building efforts can be tailored to the team's unique challenges, context, and needs (Klein et al., 2009; Lacerenza et al., 2018; Shuffler et al., 2018). A scientifically based team-building intervention capable of helping a team overcome its obstacles will focus on one or more of the following: goal-setting, interpersonal relationships, role clarification, and problem-solving (Shuffler et al., 2018). One meta-analysis showed that all four of these focus areas engender positive effects on team outcomes, with goal-setting and role clarification exerting the strongest effect (Klein et al., 2009). All members of a science team can play an active role in designing a team-building intervention, including identifying and communicating any challenges to be addressed. If, for example, a team determines that improving interpersonal relationships is the priority, a team-building strategy could include creating time for informal, social experiences, such as sharing a meal between or after working sessions. In a presentation to the committee, Emily Ackerman (Harvard Medical School) emphasized that team-building interventions can prioritize participation, considering as needed the physical aspects of a location, the timing and cost of the activity, and the social complexity and sensory levels involved.[5]

Best Practice: Developing a Shared Language

Effective communication and information-sharing are the core of successful teamwork. Communication can allow team members to exchange and integrate their varying knowledge, skills, and expertise, which can be critical in addressing the complex, interdisciplinary problems that science teams often face. Communication can facilitate team coordination, problem-solving, and goal alignment, ensuring that all members contribute meaningfully to the team's objectives. Effective communication facilitates critical team processes, such as team learning behaviors, where members actively share knowledge, ask questions, and clarify misunderstandings (Harvey et al., 2022; Wiese et al., 2022). In addition, communication plays a pivotal role in whether critical key emergent states, such as psychological safety, emerge sufficiently (Frazier et al., 2017). In this way, communication drives task execution and fosters the conditions necessary for sustained team success. Communication is essential throughout all team phases and tasks, but given the importance of generating a shared language during the development phase, relevant evidence is presented here. Without clear

[5] Presentation to the committee April 10, 2024.

communication, the flow of critical information can be disrupted, leading to inefficiencies, misunderstandings, and ultimately ineffective performance.

To communicate effectively, teams can develop a shared team language and vocabulary, especially for inter- and transdisciplinary efforts. Cross-training efforts within the team are helpful to this end, where members share key concepts and terminology from their respective disciplines that are relevant to the project (Falcone et al., 2019; Henson et al., 2020). The use of analogies may be particularly suitable for cross-disciplinary teams, as they can demonstrate individual team members' knowledge application in more widely relevant ways (Graff & Clark, 2018) and uncover and bridge differences in how a team understands a shared project (Paletz et al., 2013). Similarly, integrating keywords from individual team members' areas of study into a common team glossary can facilitate improved communication by ensuring team members either are using the same words in the same ways or are aware of discrepancies. In case of discrepancies, teams can benefit from collectively redefining terms or arriving at an alternative vocabulary. When possible, identifying and avoiding discipline-specific jargon can reduce frustrations and misunderstandings and contribute to team effectiveness (Henson et al., 2020).

Modes of communication are a key consideration throughout all project stages. Promoting communication practices such as the use of qualified and vetted sign language interpreters and real-time captioning and embracing different communication styles can help science teams unlock the full array of information and lived experiences to advance knowledge production and innovation. AI technology can also help facilitate communication that can increase participation, including through real-time translation tools (Johnson et al., 2017). When participating in cross-training activities, teams can strive to use plain language summaries. Visuals can also be used to support text and speech, but not as the only means of communication.

Development Phase Summary

The development phase focuses on critical team processes such as generating shared goals, developing critical awareness, externalizing group cognition, and establishing a psychologically safe environment. Careful attention to best practices pertaining to team assembly, team onboarding and building, and developing a shared language can set team members up for success and help them understand and respect one another's different perspectives, lived experiences, and values; engage in co-learning; and find common ground. This is crucial for effective knowledge integration during the conceptualization phase.

Phase II: Conceptualization

In the conceptualization phase of a research project, science teams develop research questions and hypotheses, build conceptual models, and agree on research designs and plans (Hall et al., 2012). As such, this phase establishes the directions a science team's research will take. Essential team phenomena during this stage include developing shared mental models regarding taskwork and teamwork, continuing to generate a shared language, and fostering team norms and values (Hall et al., 2012). These processes ensure that team members have a common understanding of the project's team, methods, and expected outcomes, which is essential for effective collaboration.

Best Practice: Team Charters

A *team charter* is a "formal document written by team members at the outset of a team's life cycle that specifies acceptable behaviors in the team" (Courtright et al., 2017, p. 1462). Also known as a science prenup (Bennett et al., 2018), charters establish the foundation for effective team science by clarifying what teams will achieve, how they will accomplish their work, who will do what, and when the team will accomplish deliverables. Charters fit within the broader space of collaboration planning, a concept encompassing many factors that can affect taskwork and teamwork (Hall et al., 2019; Woolley et al., 2008) and are recommended as an activity to support teams (Shuffler et al., 2018). When formulated at the beginning of team interaction, ideally before the team has performed any work, charters operate as a psychological contract by setting mutual expectations and operating procedures and outlining what success looks like (Egeland & Schei, 2015). By helping the team agree on conflict resolution strategies and plan for potential challenges, such as authorship disputes, before they occur, misunderstandings regarding work effort and quality can be eliminated or reduced. Therefore, reviews in the broader team literature (Shuffler et al., 2018), the science team literature (Hall et al., 2019), and the translational science team literature (e.g., Begerowski et al., 2021) regard team charters as an evidence-based team development intervention for improving performance trajectories. Although typically implemented in smaller teams, research has also identified team charters as a best practice in multiteam systems (i.e., teams of teams; Carter et al., 2019).

Although widely implemented in practice, empirical research on team charters is limited in volume and sample, with most studies using non-science teams and students (e.g., Aaron et al., 2014; Courtright et al., 2017; Egeland et al., 2017; Johnson et al., 2022; Mathieu & Rapp, 2009; McDowell et al., 2011). However, existing research concurs that team charters positively predict team functioning and processes and are associated with higher levels of communication, effort, mutual support, cohesion (Aaron et al., 2014; McDowell et al., 2011), member satisfaction (Aaron et al., 2014), motivation, team efficacy (Johnson et al., 2022), and information integration (Woolley et al., 2008).

Although team charters tend not to influence team performance directly (e.g., Courtright et al., 2017; Johnson et al., 2022), studies have demonstrated team performance enhancements when team charters were combined with task-appropriate expertise (Woolley et al., 2008) and taskwork performance strategies (Mathieu & Rapp, 2009). Task cohesion has been found to be a key mediator of the team charter quality–team performance relationship (Courtright et al., 2017). In addition, charters boosted team performance by enhancing teams' ability to navigate disruptions (Egeland et al., 2017). Team charters can potentially further promote psychological safety, particularly for heterogeneous science teams, through methods such as establishing clear policies around including those with individual differences, codifying flexible schedules and remote work options to accommodate different working styles and needs of all team members, designating specific channels or individuals as points of contact for team members to feel safe disclosing their concerns or needs, and establishing not only clear ground rules for operating as a team but also protocols for how to address grievances or rectify harm when rules are not followed.

Team charter creation can diverge in significant ways, with the final product being a written document that outlines the team's purpose, objectives, responsibilities, and operational procedures. In some studies, team members prepared responses independently prior to group discussion (e.g., Mathieu & Rapp, 2009). In addition, some teams used trained facilitators to guide members through topics, probe for deeper insight, and request participation from all members (e.g., Rolland et al., 2021b). Topics discussed vary substantially, given differences in the type of team and the nature of team tasks (e.g., Egeland et al., 2017; Hall et al., 2019; Mathieu & Rapp, 2009). To illustrate, one group identified ten components to address in a collaboration plan for science teams (Hall et al., 2019):

1. Rationale for team approach—is a team needed—and team composition in terms of what expertise and how many members need to be included
2. Individual, team, and institutional collaboration readiness
3. Technological readiness
4. Team functioning
5. Communication and coordination
6. Leadership, management, and administration
7. Conflict prevention and management

8. Training
9. Quality improvement activities, including metrics
10. Budget and resource allocation. (pp. 591–601)

Interdisciplinary science teams also need guidance on authorship policies, data and information management, and conflict management (Rolland et al., 2021a). Many science teams qualify as multiteam systems (Carter et al., 2019), necessitating that multiteam charters include identifying boundary spanners between component teams, determining inter-team leadership, agreeing on how team goals will be aligned, and anticipating inter-team friction (Asencio et al., 2012).

Although conflict is often seen as something to avoid, it is an inevitable aspect of teamwork and even a necessary component of collaboration, especially in scientific contexts where various viewpoints are essential for innovation and problem-solving (Fiore et al., 2015). Conflict arises when individuals bring unique perspectives and experiences to the table, leading to differing interpretations of the problem space (Weingart et al., 2015). These differences create perception gaps, where team members have varying understandings of the task at hand. Research on conflict resolution in science teams is scarce; however, a first step toward developing a conflict management protocol is distinguishing between the three types of conflict types identified in the literature: task, relationship, and procedural/process (Jehn, 1997; O'Neill et al., 2013).

Task conflict refers to disagreements related to the content and outcomes of the team's work, focusing on ideas, viewpoints, and strategies. When facing task conflict, fostering mutual understanding across team members, such as through facilitated discussions guided by the Toolbox Dialogue Initiative, as mentioned in the development phase, could be effective (Hubbs et al., 2020). *Relationship conflict*, on the other hand, involves personal disagreements and interpersonal tensions that are not task-related, often stemming from personality clashes or emotional incompatibilities. Highly intentional approaches to team member selection that work to surface individual orientations, values, and personalities during team assembly could help mitigate potential relationship conflicts; however, an impartial external facilitator may best handle relationship conflicts that emerge in later stages of teaming. Finally, *process conflict* arises from disagreements about how the team's work, such as task delegation and timelines, will be carried out. A strong team charter can specify roles, responsibilities, and timelines to which every member of the team is asked to agree.

Whereas some studies have examined the simple existence of a charter (e.g., Egeland et al., 2017; Rolland et al., 2021a), others have emphasized the importance of charter quality (Courtright et al., 2017; Mathieu & Rapp, 2009). High charter quality is characterized as being detailed; broad in scope, covering more aspects of team functioning; and high on professionalism, where the "content of the team charter is clearly and consistently laid out and is presented in a form that makes its content understandable" (Courtright et al., 2017, p. 1464). In addition to quality, a team's engagement with its charter throughout its life cycle is an important consideration. In a study of nearly 1,900 teams, one group found that implementing a charter at the beginning of a team's life cycle can help improve its processes (Johnson et al., 2022).

Regardless of the exact form a team charter takes or how it is developed, science teams will benefit when all members, including late-joining ones, are included in the charter development process; the discussion fosters trust, commitment, and buy-in for decisions that affect subsequent team interactions (Rolland et al., 2021a). All members of a science team can review and sign off on the written product, ensuring a mutual agreement and commitment to the charter's principles (Byrd & Luthy, 2010). Science teams can both adhere to the content of their team charter and treat it like a living document that requires periodic review and updating to evolve with the team (Mathieu & Rapp, 2009).

Best Practice: Team Planning and Project Design

When establishing a team charter and developing a project design, science teams need to engage in extensive team planning. Team planning refers to the processes through which a team sets goals, defines roles, outlines tasks, and organizes resources collaboratively to achieve a shared objective. It might involve creating a strategy that aligns the team's efforts and ensures all members are working toward common outcomes. For instance, developing collaborative research questions and hypotheses may require revisiting the team's inventory of expertise, interests, capacities, resources, and timelines to identify points of integration among team members.

Unfortunately, many teams struggle to plan effectively. The broader literature on team functioning emphasizes that teams often exhibit critical process losses during planning that can severely limit the effectiveness of team plans (Montoya et al., 2015). For instance, team planning can be hindered by a tendency for teams to focus on and discuss shared information all team members know, rather than discussing unique information that only one or a few members possess (Stasser & Titus, 1985). This shared information bias can limit a team's ability to make optimal decisions, as critical insights may be overlooked. Prediscussion preferences can also create challenges, as team members often enter discussions with preconceived ideas, making it difficult to integrate new information. This can result in decisions being based on entrenched opinions rather than logical evaluation of all available data.

Uneven participation in discussion is another common issue, particularly in larger teams or those with individuals who have dominant personalities. Another problem is *group escalation,* which refers to the tendency of teams, especially highly cohesive ones, to commit to poor decisions resulting from pressures for conformity (Liao et al., 2004). Group escalation can lead to overconfidence and a failure to explore alternative options thoroughly. Moreover, teams often experience planning aversion, where they skip the planning phase entirely, particularly when under pressure to act quickly (Montoya et al., 2015). A lack of structured planning leaves teams unprepared when faced with unexpected challenges (Montoya et al., 2015). Each of these issues highlights the need for careful management and strategies to ensure effective team planning and decision-making.

To mitigate the typical problems associated with team planning, teams may need to implement a series of interventions. For example, to mitigate the tendencies for prediscussion preferences or shared information to dominate the conversation, leaders might frame the planning process as a problem-solving task rather than a judgment-based one. When teams focus on solving a problem, they are more likely to exchange novel insights and explore new solutions rather than merely validating existing opinions (Griffin & Guez, 2014). This approach encourages teams to gather all relevant information before making decisions, similar to methods used in creativity research (Wang & Nickerson, 2017).

Matching approaches, disciplines, and methodologies to the problem's demands, rather than to any individual's attachments, is important for designing a study capable of addressing the complex problem or question identified. Because they are engaged in complex problem-solving, science teams often rely on boundary objects to scaffold their understanding of a problem and its elements (Star & Griesemer, 1989). Scholars originally conceived of *boundary objects* as "inhabit[ing] several intersecting social worlds and satisfy[ing] the informational requirements of each of them" (Star & Griesemer, 1989, p. 393). Boundary objects can be used to align individual work in multidisciplinary teams, for instance, or to produce novel pathways for more engaged collaboration outside an existing field or discipline.

For example, systems mapping can help a team match a collaboration to a problem of interest by identifying and displaying the interlinkages of relevant components, connections, and interested parties and then deciding what is in versus out (e.g., Braithwaite et al., 2018). A systems map can be seen as a type of boundary object through which members of a science team understand their project's collective goals, how they contribute to those goals, and how their efforts intersect with those of others on the team. In collaborative problem-solving, these types of co-constructed artifacts have taken different names, including process-based descriptions, such as *model-based reasoning* (Pennington et al., 2021), *external representations* (Fiore & Schooler, 2004), *cognitive artifacts* (Fiore et al., 2010; Hutchins, 1999), and *coordination artifacts* (Schmidt & Wagner, 2004).

To foster knowledge integration in science teams, some intervention research has incorporated cognitive artifacts with teamwork processes. One group developed a program based on the cognitive and learning sciences, where science team members worked to integrate internal mental models of a problem with externalized or visual forms co-created with their team (Pennington, 2016; Pennington et al., 2016, 2021). Although there has been some evidence of attitudinal changes following this intervention, it has yet to be tested rigorously. Any material or processual artifact could be considered a boundary object, so long as it holds meaning for each individual member of a team and facilitates collaboration through the shared mental models or understanding it promotes across the team. As such, boundary objects can support inclusive design for team science (Star, 2010).

Another approach science teams may use to leverage collective knowledge and strengths into integrative project designs is *perspective-taking*, where individuals adopt other team members' viewpoints on a topic to better appreciate differences across backgrounds and fields and integrate disparate perspectives into a cohesive team vision (Hoever et al., 2012). Boundary objects could represent a useful starting point for perspective-taking activities, as members of a science team try to reflect on the same object from an intersecting lens other than their own.

Open dialogue around assumptions and disciplinary standards is a proven means of fostering integration in science teams (Piso et al., 2016). It is also important to practice and promote epistemic humility, which involves encouraging team members to be open about the strengths and limitations of their disciplines and to develop respect for and engage with new ways of knowing (Boix Mansilla, 2006, 2017). This practice can be informative to other team members, who may be unaware of the constraints present in other disciplines and other organizations (Castillo et al., 2024). Boundary objects, cross-training, and dialogue during team planning and project design can together help science teams avoid *disciplinary capture*, or scenarios in which one of the collaborating disciplines overshadows the others in terms of decisions made and research directions taken, hampering the integrative potential of a team science approach (Brister, 2016).

Planning the taskwork is integral to improving team processes and outcomes (Shuffler et al., 2018). Although sources in the literature recommend certain task-based strategies—such as building in task interdependencies to encourage team trust and cohesion (De Jong et al., 2016) and holding regular team check-ins to foster information exchange and team learning—team members' preferences and needs (e.g., working style, platforms, and interdependence) need to be taken into account for motivation to remain high (Park et al., 2013). In the committee's experience, failure to account for such preferences during team planning and project design can result in frustration and even team member attrition.

To improve decision-making during planning, teams could also allocate time to discuss alternative strategies rather than focusing solely on initial preferences. This increases the likelihood of identifying effective solutions and avoiding decisions based on entrenched views (Tschan et al., 2009). Including members with conflicting preferences can stimulate richer discussions, as dissenting opinions push teams to engage in deeper, more critical evaluations (Schweiger et al., 1989). Ensuring that team members develop accurate cognitive models of the task and environment also helps, particularly in reactive situations. Leaders can play a key role in guiding teams to consider different perspectives and avoid fixating on initial assumptions.

Small groups naturally promote participation, as individuals feel a sense of responsibility to contribute (Dening et al., 2022). However, large groups may require different strategies. For example, leveraging asynchronous virtual communication platforms, such as message boards or chat rooms, can provide quieter members an opportunity to contribute, reducing the dominance of more vocal team members. In addition, counteracting the tendency to exert less energy when working in a group than as an individual and uneven participation is important (Dening et al., 2022). Teams can address motivation losses by increasing cohesion, identifying individual contributions, and holding members accountable for their input (Berengüí et al., 2021; Braun & Avital, 2006; Cady et al., 2018; Stewart et al., 2023; Whitworth & Biddle, 2007).

Finally, it is essential for teams to allocate sufficient time for planning. Without designated planning time, teams may skip this critical phase and resort to reactive decision-making. Using formal planning tools, such as charters or strategy outlines as discussed in the previous section, can ensure that key points are addressed during discussions. Teams under heavy performance demands can use low-workload periods to engage in planning, ensuring that preparation is not neglected when pressure mounts. Promoting a cohesive climate and setting challenging goals can further motivate teams to invest in detailed planning, recognizing the complexity of tasks ahead and the need for thorough strategies.

Conceptualization Phase Summary

The conceptualization phase emphasizes the importance of laying strong, synergistic foundations for both teamwork and taskwork before any team science project begins. Best practices surrounding team charter development, team planning, and project design represent opportunities to build on team efforts in the development phase, strengthen shared mental models, and provide a clear path forward. This foundation is crucial for effective operationalization during the implementation phase.

Phase III: Implementation

In the implementation phase, science teams execute the project plans established during earlier stages (Hall et al., 2012). Even when science teams have diligently followed best practices during the development and conceptualization phases, the transition to implementation is rarely seamless. During this phase, teams need to engage in several complex processes, such as experiment execution, that require integrating teamwork and taskwork. It is important for the team to periodically revisit and ensure alignment with its shared goals and vision. Effectively engaging in the implementation phase requires regular interactions among team members, sustained effort, and continuous monitoring of progress toward scientific goals. This includes communicating openly, providing backup support when needed, giving constructive feedback, and coordinating actions according to task demands (Hall et al., 2012; Marks et al., 2001). In the following sections, the committee provides a detailed overview of two critical best practices—project management and team debriefs—during the implementation phase.

Best Practice: Project Management

Once a team enters the implementation phase of its scientific work, managing the project effectively becomes essential. *Project management* involves the systematic and deliberate application of knowledge, tools, and expertise to ensure the successful completion of complex projects in a timely and efficient manner (Sutton et al., 2019; Wuchty et al., 2007). A cornucopia of project management practices has been shown to work outside of science teams, and programs are being developed for implementing these practices in the science team context (Brasier et al., 2023a; Steiner et al., 2023; Sutton et al., 2019). Project management, however, is not limited to a single individual within the team. Multiple members can engage in project management activities, contributing to task organization, communication, and coordination across the team. In the following, the committee highlights some of the best practices most applicable to science teams.

Team Meetings. Over the past 2 decades, an entire science devoted to understanding team meetings has developed (Rogelberg, 2019; Rogelberg et al., 2006; Wolf et al., 2024). Meetings can enhance collaboration, facilitate exchanging information, and improve decision-making by providing a structured platform for communication and coordination (Allen & Rogelberg, 2013). When managed properly, meetings can foster employee engagement, promote team cohesion, and align individual tasks with broader team goals (Mroz et al., 2018). Moreover, well-facilitated meetings can create a space for shared leadership and help balance individual and team-wide objectives, which are particularly important in multiteam systems (Wolf et al., 2024).

On the other hand, poorly run team meetings can lead to disengagement, frustration, and wasted time. And if meetings are too frequent, too long, or lack clear objectives, they can contribute to meeting fatigue and reduce productivity (Allen et al., 2012; Mroz et al., 2018). In multiteam systems, an overemphasis on meetings without sufficient inter-team task interdependence can be counterproductive, hindering performance and collaboration (Wolf et al., 2024). In addition, meetings that do not encourage participation or are dominated by a few voices can lead to missed opportunities for varying input and innovation (Allen & Rogelberg, 2013). Meetings and discussions can also be exclusionary if they do not incorporate accessible solutions such as sign language interpreters, real-time captioning, or assistive listening devices when needed.

Several strategies can help science teams maximize the effectiveness of their meetings. Key practices include having a clear agenda, starting and ending meetings on time, and ensuring that only essential personnel are present (Mroz et al., 2018). These strategies not only help meetings run efficiently but also avoid wasting time for individuals whose presence may not be required. In addition, those responsible for managing meetings can regularly assess whether a meeting is truly necessary. If there is no pressing need to meet, even for regularly scheduled meetings, it is entirely appropriate to cancel them (Rogelberg, 2019). Those managing the meeting can also play a crucial role in creating a welcoming environment where all participants feel psychologically safe to share their ideas and perspectives (Allen & Rogelberg, 2013). This promotes open communication and collaboration. In multiteam systems, managing meetings can be more complex, but maintaining a balance between team-specific and system-wide goals is essential for sustaining productivity (Wolf et al., 2024). Finally, regular feedback and follow-up on meeting outcomes, such as distributing meeting minutes and reviewing action items, are critical for ensuring accountability, maintaining momentum, and maximizing the effectiveness of team meetings (Rogelberg et al., 2006; Wolf et al., 2024). Artificial intelligence (AI) tools, such as Otter.ai, ChatGPT, and Fireflies.ai, can be effective in transcribing meetings and summarizing key points and discussion for later access by all team. In the context of science teams acting as multiteam systems, it is recommended that meeting preparation and planning be incorporated into the multiteam charter (Asencio et al., 2012).

Facilitation. Facilitators, whether internal or external to a collaboration, can help science teams make the most of their meetings together. With a focus on both the activities and interactions of teams (Bens, 2012), facilitators integrate teamwork and taskwork holistically to achieve meeting goals (Wróbel et al., 2021). Science team meetings can benefit from facilitation in a more traditional sense, whereby a facilitator consults on meeting design, tracks progress and time, fosters equitable and inclusive conversations, and establishes the right meeting tone and environment (Wardale, 2013; Wróbel et al, 2021). Conventional facilitation can further help science teams structure and guide crucial processes such as problem-solving, reaching consensus, decision-making, conflict resolution, and navigating different stages of a team (e.g., forming, norming, storming, performing; Kaner, 2014; Tuckman, 1965). Through thoughtful and intentional team interactions, facilitation can enhance idea generation (Kramer et al., 2001) and engagement (Parker, 2020) as important contributors to overall team performance. However, recent work has pointed to the need for facilitation practices designed specifically for boundary-spanning science teams (Cravens et al., 2022; Graef et al., 2021a,b).

One group proposed that science facilitation uniquely intersects collaborative science expertise with interpersonal expertise to align with the distinct purpose and challenges of knowledge-producing teams (Cravens et al., 2022). Meetings, then, are opportunities for science facilitators to create enabling conditions for "resolving many of the interpersonal and conceptual challenges of interdisciplinarity" (Graef et al., 2021b, p. 109). Challenges unique to science teams include navigating the ambiguity of novel cross-disciplinary collaborations, reconciling epistemic discrepancies, partnering with nonscientists, and negotiating disparate scientific priorities and approaches into a cohesive project capable of solving a real-world problem. Science facilitators can integrate these team science challenges into meeting activities and design (Graef et al., 2021a), and thus capitalize on meetings' immense potential to contribute to the collaborative research process (Graef et al., 2021b).

For example, science facilitators can guide scientific visioning in a team meeting by creating a shared conceptual framework. In doing so, they can help science teams bridge cross-disciplinary communication, identify points of scientific contention, and prompt for linkages and uncertainties until achieving an inspiring, integrated vision that represents and holds meaning for every individual on a team. A science facilitator can also help a team match its meeting sessions to its phase in the scientific process. During conceptualization, a science facilitator may prioritize sessions featuring whole-group discussions where everyone can share their perspective with and learn from the full array of collaborators. A science facilitator can, however, recognize that session formats during the implementation phase may need to shift to small breakouts based on tasks or even to individual quiet working time. In these ways, science facilitation can operationalize the intersection between collaborative science and interpersonal dynamics to advance team science (Hall et al., 2018).

Communication Management. As indicated throughout this chapter, communication is vitally important for the success of science teams. However, no matter how much planning is done in the development and conceptualization phases, communication challenges are inevitable when the implementation phase begins. Factors such as disciplinary silos, power dynamics, differing communication styles, and coordination across time zones and locations can create communication challenges for science teams (e.g., O'Rourke et al., 2023). Still, actions can be taken during the implementation phase to mitigate some of these challenges.

One general best practice is fostering a structured dialogue that creates an environment conducive to purposeful and meaningful exchanges among team members. Teams can prioritize cultivating a positive communication culture where all members feel safe and encouraged to share their perspectives, as this leads to more successful outcomes (Cason et al., 2020; Hubbs et al., 2020; O'Rourke et al., 2023). In addition, structured feedback mechanisms, such as regular updates or debriefs (discussed in greater detail later), are essential for maintaining productive communication during the implementation phase. Even in teams with generally effective communication, it is important to monitor interactions for acute challenges that, if left unchecked, can develop into chronic communication issues (O'Rourke et al., 2023).

A particularly effective practice is *turn-taking*, which ensures more even distribution of speaking opportunities in team meetings, allowing team members to share the floor rather than letting a few individuals dominate the conversation. Any team member, whether the leader, a participant, or an external facilitator, can implement turn-taking. One case study of using an external facilitator found that teams practicing even turn-taking tended to have higher success rates because it promoted the balanced exchange of ideas and enhanced collective problem-solving (Love et al., 2022). Although interactional best practices, such as turn-taking and creating space for social time, can be incorporated into virtual team settings, the consensus in the literature is that in-person meetings with face-to-face communication lead to more effective team science, especially during times of problem-solving and trust-building (Henson et al., 2020; Zajdela et al., 2025).

As the project matures, teams may consider developing information-exchange protocols that consider team members' preferences to stipulate when, how, and to whom project updates or information will be communicated (Zajac et al., 2021), with quality of communication prioritized over quantity (Marlow et al., 2018). During check-in meetings, it is important for team members to discuss more than surface-level updates and instead share honest responses around successes, failures, and unknowns. Allowing other members of the team to process such information can lead to improved understanding of where another member of the team can be deployed to help solve a problem, for example. In addition to discussions, it is also important to determine specific next steps to be taken between regular check-ins to ensure forward momentum is maintained.

Monitoring and Assessment. Ongoing monitoring and assessment during the implementation phase is a crucial best practice (see also Chapter 5). Having a clear understanding of how the team is performing at any given time is beneficial, but there are specific considerations regarding what is being monitored, when it is monitored, and how the monitoring is conducted. First, it is essential to target specific attributes of the team to assess. Teams can be evaluated on various factors such as performance outcomes (e.g., quality, accuracy, and timeliness of the work produced) or on process and emergent state metrics (e.g., satisfaction, trust, cohesion; Rosen et al., 2008; Shuffler et al., 2018). When deciding what to measure, those managing a project need to consider whether the assessed factors are related to the team's overall goals directly. For example, if the goal is to foster innovation, the team could measure factors such as creativity, the generation of new ideas, and disciplinary integration rather than focusing solely on traditional productivity metrics such as the number of papers published or the speed of task completion.

It is equally important to assess when to measure these dynamics. Some emergent states, such as trust, psychological safety, and cohesion, might be more meaningful when measured after significant events such as major project milestones, decision points, or conflict resolution (Carter et al., 2018; Kozlowski & Chao, 2018). Measuring team cohesion after an intense grant submission or research presentation, for example, could provide valuable insights into how the team responds to high-pressure situations and whether support mechanisms need adjustment. Other metrics, such as communication flow, may be appropriate to assess regularly throughout the project.

Finally, how a team monitors performance and process is critical for gathering actionable information. Different sources of feedback provide different perspectives, making it important to collect data from various team members, including principal investigators, junior researchers, and support staff. This variety ensures a more accurate and comprehensive team performance assessment, as each member may experience and interpret team dynamics differently (Wiese et al., 2015). Relying on a single source of feedback risks missing key insights, while integrating multiple data sources can highlight patterns, uncover hidden challenges, and support more targeted interventions.

Project Management Tools. Although the published research in the science team domain is limited, several tools have been identified for enhancing the project management process significantly. *Project management tools* are platforms, software, and structured methods that help organize, monitor, and manage project tasks, timelines, resources, and communications efficiently. These tools aim to streamline operations, reduce bottlenecks, and ensure that team efforts are well-coordinated for achieving project goals. Anecdotally, science teams often utilize such tools, but research on their specific applications in this context is still emerging, with recent studies highlighting their potential effectiveness (e.g., Gaffney et al., 2019; Steiner et al., 2023; Timóteo et al., 2021)

For example, one study examined the use of project management tools in a large, multisite lung cancer screening consortium to facilitate collaboration, efficiency, and productivity (Steiner et al., 2023). The tools employed in this case study included platforms such as SmartSheet for managing work plans, tracking data acquisition timelines, and maintaining project deliverables. In addition, the project used SharePoint and Microsoft Teams for document management and team communication, providing a centralized system for all sites to access essential documents and updates in real time. These tools allowed the team to maintain transparency; track progress; and coordinate complex, multisite research activities effectively.

Efficient resource-sharing is another key component of project management. Sharing resources such as data, software, and findings in real time can reduce duplication of effort, accelerate the research process, and ensure that all team members have access to the most current information (Santos et al., 2012). Leveraging collaborative document tools, such as Google Docs and Microsoft Teams, can allow team members to work on shared documents in real time, reducing email overload and ensuring everyone has access to the most up-to-date information.

Many project management platforms include integrated systems for documenting and archiving communications and decisions. This capability can help science teams maintain a comprehensive record of their projects' development, which can support team communication, transparency, reproducibility, and onboarding of new members. Implementing a consistent file management system with clear folder structures and naming conventions helps everyone find information easily, further supporting efficient collaboration. Teams can additionally take steps to ensure that all documentation is in an accessible format.

AI-powered platforms can improve taskwork and teamwork by automating processes and improving coordination. These platforms streamline activities such as scheduling, task assignment, literature reviews, and document organization (e.g., Benchling, Connected Papers, ScopusAI). AI-driven project management tools can assign tasks, track progress, and automate workflows so teams can focus on high-priority tasks (Jackson, 2022). Virtual workspaces such as GrantedAI and Kudos support specific stages of a project, including grant writing and research dissemination. AI tools can foster collaboration and efficiency by automating activities and coordinating efforts.

AI can also improve data and knowledge management systems (Jarrahi et al., 2023), enabling team members to access and share information easily, while intelligent collaboration platforms can optimize task allocation and track progress (Chen et al., 2017). AI tools, such as retrieval-augmented generation (Lewis et al., 2020), can organize, index, and retrieve relevant information from large datasets, providing team members with access to resources. AI tools can also support data anonymization and privacy management (Abay et al., 2019) and directly allow global model learning without sharing sensitive information across teams (McMahan et al., 2017).

Best Practice: Team Debriefs

A *team debrief* is a formal team development intervention that "turns a recent event into a learning opportunity through a combination of task feedback, reflection, and discussion" (Keiser & Arthur, 2021, p. 1008). Conducted periodically after completing significant team activities, team debriefs are structured sessions for reviewing and analyzing a team's performance (e.g., Shuffler et al., 2018). The primary goal is to reflect on what happened, identify what went well and what went poorly, and determine ways to improve in the future (Tannenbaum & Cerasoli, 2013). A wide swath of industries, including manufacturing, education, information technology, aviation, the military, and health care, employs team debriefs (e.g., Chen et al., 2018; Duff et al., 2024; Eddy et al., 2013). The committee uses the term *team debrief* because it has been used most often in reviews of the literature (e.g., Keiser & Arthur, 2021; Shuffler et al., 2018; Tannenbaum & Cerasoli, 2013), including literature on science teams (Begerowski et al., 2021). However, other names include *after-action reviews* (e.g., Department of the Army, 1993), *post-mortem evaluations* (e.g., Kasi et al., 2008), *huddles* (e.g., Reiter-Palmon et al., 2015), *reflexivity* (e.g., Tesler et al., 2018), and *guided team self-correction* (Smith-Jentsch et al., 2008).

Research on debriefs has been conducted primarily on nonscience teams. Multiple meta-analyses demonstrate that team debriefs are associated with higher team performance (e.g., Keiser & Arthur, 2021, 2022; Tannenbaum & Cerasoli, 2013). Compared with no-debrief teams, debrief teams improved team performance and that of the individuals within teams by approximately 25% (Tannenbaum & Cerasoli, 2013). A later meta-analysis found even higher performance effects after increasing the number of included studies (Keiser & Arthur, 2021). Mediators of the team debrief–performance relationship include workload-sharing (Vashdi et al., 2012).

In addition to task performance, team debriefs can influence and improve attitudes, task knowledge, and team processes (Keiser & Arthur, 2021). Research has shown that debriefs enhance team adaptation (Abrantes et al., 2022) and leadership development (DeRue et al., 2012), and reduce decision time (Qudrat-Ullah, 2007). Meta-analyses have demonstrated the efficacy of debriefs in small (2 members), medium (3–5 members), and large (6–16 members) teams (e.g., Keiser & Arthur, 2022). In addition, debriefs are effective in both geographically dispersed and face-to-face settings (Keiser & Arthur, 2022). Furthermore, team debriefs are especially useful in high-complexity and ambiguous task environments that offer no intrinsic feedback (Keiser & Arthur, 2022). Therefore, in addition to action teams—in the military and health care—debriefs can be effective for project and decision-making tasks (Keiser & Arthur, 2022). Given the strength and generalizability of these results, debriefs are a straightforward, inexpensive, and easily implemented way to facilitate team effectiveness (e.g., Shuffler et al., 2018; Tannenbaum & Cerasoli, 2013). Based on the research conducted in the broader team literature, one analysis identified team debriefs as a central team development intervention for science teams (Begerowski et al., 2021). However, research on debriefing in science teams is needed.

Fundamental components of team debriefs include feedback, reflection, and discussion about specific performance events (Keiser & Arthur, 2021). Note that debriefs extend beyond feedback in that they are collaborative and ideally include all team members rather than just the team leader offering comments (Tannenbaum & Cerasoli, 2013). Additionally, a defining feature of team debriefs is self-learning, in which team members are actively involved in self-discovery rather than receiving feedback passively (Tannenbaum & Cerasoli, 2013). In addition, whereas traditional feedback emphasizes outcomes, the focus of debriefs is the processes that contributed to successes and failures (Allen et al., 2018; Tannenbaum & Cerasoli, 2013). Because debriefs are developmental in intent and are carried out to promote self- and team-learning, as opposed to evaluative for administrative decision-making (Tannenbaum & Cerasoli, 2013), outcome feedback regarding success or failure can be provided after debriefs (Salas et al., 2008).

Despite these similar components, there is substantial variation in how debriefs are conducted across studies and organizational settings (e.g., Eddy et al., 2013; Smith-Jentsch et al., 2008; Smith-Jentsch & Sierra, 2023). However, meta-analytic findings support using the original structure for debriefs developed by the U.S. Army (Department of the Army, 1993; Keiser & Arthur, 2022). This structure includes reviewing intended objectives, actual outcomes, effective actions, ineffective actions including near misses, intended future objectives, and the strategy for achieving the intended future objectives (Department of the Army, 1993; Keiser & Arthur, 2022). Debriefs can include asking open-ended questions, including: What were we trying to accomplish? What happened in the team event? Where did we succeed in meeting our goals? Where did we fail to meet our goals? What caused our results? What can we start, stop, and continue doing? What are the important takeaways and lessons learned? (e.g., Keiser & Arthur, 2022). Identifying actionable next steps is critical to debriefing effectively (e.g., Chen et al., 2018; Salas et al., 2008). Following the group discussion, the debrief can be paired with outcome feedback and individual or team training as needed (Salas et al., 2008).

Researchers have provided additional evidence-based best practices in response to the variability in debrief implementation (e.g., Keiser & Arthur, 2021, 2022; Salas et al., 2008; Tannenbaum & Cerasoli, 2013). For example, team debriefs can be conducted as soon as possible after completing a significant team event, such as achieving a major deliverable; time period, such as after a shift; or training, such as after a simulation (Tannenbaum & Greilich, 2023) to avoid members forgetting important details with the passage of time (Salas et al., 2008). Levels of analysis can be aligned such that tasks, training, and criteria match for individuals and teams (Keiser & Arthur, 2021; Tannenbaum & Cerasoli, 2013).

Instead of a general performance overview, debriefs can provide specific examples of competencies and deficiencies (Tannenbaum & Cerasoli, 2013). As such, it is critical to establish and maintain high psychological safety so that members feel comfortable sharing errors and mistakes in a supportive rather than judgmental environment (e.g., Kolbe et al., 2020; Salas et al., 2008). It is also advised that feedback be supported with objective data, such as text or video recordings, rather than relying solely on memory (Keiser & Arthur, 2021; Salas et al., 2008).

Although one study found that using trained facilitators in debriefing activities enhanced team performance (Tannenbaum & Cerasoli, 2013), a later meta-analysis concluded the picture was more complex (Keiser & Arthur, 2021). Specifically, individual tasks benefited the most from having a facilitator, but team tasks benefited from a self-led approach, especially when combined with objective review media (Keiser & Arthur, 2021). Additional debrief characteristics interacted with one another to affect team outcomes, requiring more nuanced implementation guidelines (Keiser & Arthur, 2021). To illustrate, a highly structured debrief was more effective for action teams, such as those in the military, whereas less structure was needed in health care and other industries (Keiser & Arthur, 2021). Moreover, shorter debriefs of a maximum of 20 minutes were best for teams, especially in health care, whereas longer debriefs of a minimum of 20 minutes may be needed for individuals to allow sufficient time to cover all the feedback (Keiser & Arthur, 2021, 2022). These results highlight the importance of considering debriefing characteristics in combination rather than implementing them in isolation (Keiser & Arthur, 2021).

Implementation Phase Summary

The implementation phase provides an opportunity for the team to sustain or reignite the initial enthusiasm for the scientific collaboration, which can help sustain long-term progress. To achieve team goals, team members need to actively interact, coordinate, and adapt. This requires project management, where actions are taken to ensure teams engage productively and stay on track, alongside regular team debriefs, which allow the team to reflect on progress, identify challenges, and adjust strategies as needed. Maintaining trust through transparency and reliability is essential during implementation. Trust fosters cooperation, promotes the sharing of resources and knowledge, and enhances the team's motivation to achieve their objectives. High levels of achievement and trust will help teams continue their work together in the translation phase.

Phase IV: Translation

Research translation is the process of moving the findings of scientific research from the laboratory environment to human studies and ultimately into policy and practical applications that affect society directly. Because research translation requires understanding both the basic science and the context in which the innovation will ultimately be applied, science teams can strategically include team members—scientists, community advocates, patients, policymakers, and industry partners—with a range of expertise, experience, and reach.

U.S. government agencies have long affirmed the role of science teams in closing the gap between scientific discoveries and the application of those discoveries into tangible outcomes. For instance, in 2011, NIH established the National Center for Advancing Translational Science (NCATS)[6] to support developing and implementing innovative processes, technologies, and methods for addressing the spectrum of human diseases and conditions affecting society. The NCATS approach is based on enabling the work of science teams that include government agencies, private-sector companies, patient advocacy groups, and other members of the scientific community. With a core value of collaborative team science culture, NCATS's strategic plan outlines goals for collaboration and partnerships in each of its four

[6] For more information, see http://ncats.nih.gov/about/about-translational-science and http://ncats.nih.gov/about/about-translational-science/spectrum

programmatic pillars. And in 2022, the CHIPS and Science Act, signed into law by President Joe Biden, affirmed this federal commitment by establishing the NSF Technology, Innovation and Partnerships (TIP) Directorate, the first new directorate in 30 years (Afful & Meiksin, 2022). TIP programs advance national competitiveness and strengthen societal impact by supporting partnerships between and among teams of researchers, practitioners, and users, enabling the co-creation of scientific discovery and thus closing the gap between discovery and societal impact (Glasgow & Emmons, 2007; Huebschmann et al., 2019).

Translational science teams face many of the same challenges of any science team and, as such, team leaders can prioritize team-building (Begerowski et al., 2021) and development (Stokols, 2010) using the best practices outlined elsewhere in this chapter.

Best Practice: Focus on Both External and Internal Validity

A well-documented challenge in public health research is the limited attention to replicating studies to explore generalizability of public health interventions across contexts (Huebschmann et al., 2019). Public health researchers have prioritized internal validity over external validity, thus limiting the ability to translate research into practice.

Best Practice: Connecting with Community Members

Science teams oriented toward research translation are described using a variety of terms. Research translation can include components of *community-based research*, *participatory research*, *community engagement*, *empowerment evaluation*, *participatory* or *community-based action research*, and *engaged research*, all of which partner scientist and nonscientist team members. Not surprisingly, including nonscientist members on science teams has varied success in producing outcomes that are readily applicable to the target community. Mercer et al. (2008) reliability tested an evaluation tool for measuring the effectiveness of community-based participatory research. Their review of the literature revealed five best practices for effective engagement with community members, including forming an advisory board, establishing research agreements that outline roles and responsibilities, leveraging group facilitation techniques and designated facilitators, holding regular meetings to keep team members engaged, and hiring team members from the community. While Mercer et al. (2008) focused specifically on mechanisms for facilitating research translation, these best practices are used in other contexts as well.

Cross-Cutting Best Practices

Certain best practices, including collaborative technologies and team leadership, transcend any one phase of a science team. As such, relevant evidence for these two best practices follows, separate from the development, conceptualization, implementation, and translation phases but pertinent to all four.

Best Practice: Incorporating Virtual Collaborative Technologies

With the advent of advanced information and communication technologies and the proliferation of their adoption that accompanied the COVID-19 lockdowns, the ways science teams are collaborating have significantly changed. As noted in Chapter 2, teams can operate entirely virtually, entirely in person, or as a hybrid team. Hybrid teams can be characterized by three key dimensions: geographic distribution, temporal dynamics, and communication richness. *Geographic distribution* refers to how team members are physically dispersed across different locations, ranging from fully collocated teams to those in which members work in entirely separate geographic areas (Handke et al., 2024). *Temporal dynamics* concern the timing and coordination of work, particularly how team members' schedules and time zones align or differ (Handke et al., 2024). Finally, *communication richness* refers to the capacity of the communication medium to carry information (Kirkman & Mathieu, 2005).

It is crucial to recognize that hybrid teams can take on various configurations depending on these characteristics. For instance, a science team studying climate change may have field researchers collecting data in remote locations while others are in laboratory settings analyzing the data in real time. This team might have some members who meet in person periodically for intensive problem-solving, while the rest of the team participates remotely from different time zones, coordinating work through collaborative platforms. Another example could be an interdisciplinary research team in which experimental biologists work in a laboratory, while computational modelers collaborate from other institutions, contributing to the project through cloud-based data sharing platforms and virtual meetings. For teams that have a large *component team distance*, referring to large geographical, cultural, functional, or disciplinary distance, these complexities can be particularly relevant. Virtual multiteam systems that are geographically dispersed, have communication barriers, and work in different time zones can struggle to navigate these configurations (Ingersoll et al., 2024). Developing communication norms, holding in-person meetings, and creating cross-team coordination roles could potentially help bridge these divides.

As virtual collaboration tools have evolved to facilitate science teamwork, it is important to consider the team's specific configuration and how this configuration may change over time when assessing virtual collaboration tools' use and effectiveness (e.g., Gibson et al., 2022). Compared with in-person teams, virtual and hybrid teams have different challenges when it comes to achieving team effectiveness, many of which are mediated by or dependent on virtual collaboration tools (Brucks & Levav, 2022; Handke et al., 2024; Purvanova & Kenda, 2022). When applied thoughtfully, virtual collaboration tools can help enhance communication, foster collaboration across geographic and temporal boundaries, and support flexible, adaptable, and efficient team functioning, regardless of how the team is configured.

Technology–Team Member Interactions

When adopting, configuring, or implementing a technological tool, it is crucial to consider how team members may interact with the tool to best facilitate team dynamics. As suggested above, while these tools offer several benefits, the success of their implementation depends largely on how well they align with team members' skills, needs, and comfort levels (e.g., Larson & DeChurch, 2020). Misalignment can lead to inefficiencies and frustration, mitigating the likelihood that these tools will facilitate scientific collaboration, and potentially contributing to suboptimal virtual team outcomes (e.g., Larson & DeChurch, 2020; Waizenegger et al., 2020).

One key factor to consider is team members' familiarity and comfortability with technology. While many constructs and scales are available (Holcomb et al., 2004; Martínez-Córcoles et al., 2017; Mason et al., 2014; Merritt et al., 2013; Montag et al., 2023; Sindermann et al., 2021; Sinkovics et al., 2002), the shared premise across these constructs is understanding an individual's comfortability and, consequently, propensity to engage with technologies. Individual dispositions toward technology, as well as learned or situational factors, can play a critical role in how effectively people adopt and use these technologies within the team (Hoff & Bashir, 2015). When team members are comfortable with the technology, they are more likely to engage with it fully, taking advantage of its features to enhance team communication and coordination (e.g., Colbert et al., 2016; Kilcullen et al., 2022). On the other hand, a lack of familiarity can create barriers, preventing team members from adopting new tools or leading to inefficient use of existing ones.

For example, in a science team working across multiple institutions, unfamiliarity with new collaboration software can create significant challenges. If team members struggle to use key features such as document editing or data management, this can lead to miscommunication about research findings, delays in decision-making, or even missed opportunities for collaboration. Instead of facilitating effective communication and collaboration, the software becomes a barrier, requiring extra time to troubleshoot. This disruption can detract from the team's focus on critical scientific tasks, leading to frustration and negatively impacting overall team performance and morale.

Thus, it is critical for team members to feel comfortable using technological tools. This can be achieved through targeted training sessions that familiarize members with the tools they will be using and allow them to practice in a low-pressure environment. Exposure to technological tools can facilitate their use of these technologies and decrease anxiety surrounding them (e.g., Sherrill et al., 2022). That is, training not only helps individuals gain competence but also promotes collective confidence in using the tools effectively.

Another crucial consideration when selecting and using technological tools is their accessibility for virtual and hybrid work. While many tools claim to support seamless remote collaboration, not all are accessible to all team members, particularly team members with disabilities[7] (Doush et al., 2023; Hersh et al., 2024). For instance, video conferencing software that lacks closed captioning can present barriers for D/deaf or hard-of-hearing team members. Similarly, tools with complex interfaces or high bandwidth requirements may exclude team members with limited technical capabilities or unreliable internet connections. Another accessibility challenge comes to bear when considering those who are blind or have low vision. Tools that are incompatible with screen readers, for example, can make it difficult for blind or low-vision team members to contribute effectively (Leporini et al., 2023). In a related vein, tools that require extensive use of a computer mouse may not be suitable for people with different physical abilities (e.g., Marchant et al., 2005; Trewin & Pain, 1999). As such, ensuring that all tools are accessible to all team members—showing consideration for their individual and differing needs and enabling their participation without placing undue burden—is a key component of fostering an effective team environment.

Establishing Norms

Technological tools often include a wide range of features—such as screen sharing, instant messaging, hand raising, and file sharing—designed to facilitate communication and collaboration. While these are useful,

[7] The committee acknowledges that identity-related terminology is complex, personal, and continuously evolving, and that the language used to refer to disabled communities (i.e., person-first vs. identity-first) differs by community and by individual.

without clear norms and expectations about how such functions will be used, teams may experience confusion, inefficiency, or frustration in their collaboration (Kilcullen et al., 2022).

For example, teams may end up violating data privacy agreements when norms surrounding these technologies are not established. Consider a laboratory using a multifunction project management platform that includes features for chat, video conferencing, file sharing, and data storage. Although the technology is convenient and could technically handle file sharing, it may not meet the data protection standards required for the sensitive research the team is conducting (see Chapter 4). Without established file sharing norms, team members could share sensitive files through this platform, inadvertently violating data privacy regulations.

Relatedly, establishing clear norms around the use of these tools is essential for promoting effective collaboration for everyone on the team (e.g., Gibson et al., 2014; Kirkman et al., 2002; Kirkman & Stoverink, 2021). This is particularly important in the context of team science, which frequently involves researchers from different disciplines, cultures, and language abilities (especially for non-native speakers of a primary team language) who bring unique skills and knowledge to a project. Virtual collaboration tools, such as speech-to-text features, can help foster communication and understanding by bridging language barriers or assisting team members who are D/deaf or hard of hearing. For D/deaf and hard-of-hearing team members, these tools can be tremendously beneficial in facilitating participation (e.g., Alshawabkeh et al., 2021; Ang et al., 2022). However, it is important to note that while automated speech-to-text technologies can be helpful, their use in transcripts is not considered compliant with the Americans with Disabilities Act (2010) if the content differs from the audio-only content; teams ought to be mindful of such limitations when setting expectations for accessibility. While speech-to-text technologies may work sufficiently to increase participation ease for D/deaf and hard-of-hearing team members, they are not as effective as live interpreters, who can more effectively convey aspects such as tone and nuance (Secară & Perez, 2022).

Beyond immediate accessibility, these tools can integrate different viewpoints by providing structured platforms for communication, data sharing, and collaborative problem-solving. The flexibility these tools offer can allow geospatially distributed team members to meet synchronously, and contribute asynchronously, making it possible for teams who may not have had the opportunity otherwise to work together effectively (Meluso et al., 2022). Importantly, it is not just the tools themselves that can foster this, but the thoughtful design, implementation, and norms that guide their use. By co-creating and adopting norms, the team can ensure that everyone has an equal opportunity to contribute to the team.

Data Security and Use

Data security and use is a critical aspect of information technology, and data sharing is a unique challenge for team science.

Addressing these barriers requires a nuanced understanding of how data security practices can inadvertently exclude certain groups or reinforce existing inequities, and many teams may be ill-equipped and may not understand or anticipate these issues when building teams (e.g., Law, 2023). Governance structures that include different perspectives are more likely to develop comprehensive security policies that address the needs of the population (Grindstaff & Mascarenhas, 2019). Data security protocols often assume a one-size-fits-all approach that may not consider the cultural and linguistic differences of users. For example, security warnings and protocols that are not localized or adapted to different languages and cultural contexts may lead to misunderstandings and noncompliance, posing a significant barrier. Data security measures, while crucial, often enhance complexity in system design, which can disproportionately affect those with disabilities or those who are less technologically proficient. For instance, complex authentication processes can be a hurdle for users with cognitive disabilities or who are blind or have low vision. Studies have highlighted the need for adaptive technologies that comply with security standards while also being accessible, ensuring that security enhancements do not hinder usability (Wentz et al., 2011).

The development of security technologies, such as biometric authentication systems, has raised concerns about built-in biases. Studies have shown, for instance, that facial recognition technologies have lower accuracy rates for women and people of color than for White males (Buolamwini & Gebru, 2018). This raises concerns and questions about the fairness of security measures. Some groups often face greater risks of surveillance and privacy violations, which can deter their participation in digital platforms where their data might be insecure (Bacchini & Lorusso, 2019). Ensuring that data security measures protect all users is crucial, particularly for populations who may be disproportionately affected by data gathering and data breaches (Goldshtein et al., 2024).

In addition to these concerns, there are several emerging questions regarding technology and data use, and the ways in which they may function as a barrier to team inclusion. For example, AI technology is increasingly included in many personnel decisions, such as applicant screening. Some evidence suggests that algorithms may introduce biases, and additional research is needed to understand the full effects of possible biases impacts on teams (Albaroudi et al., 2024; Tilmes, 2022). Furthermore, in instances where demographic data are involved, careful consideration can be taken into the security of these data, particularly when their public disclosure could cause the individual harm (Calabro, 2018). This can be applicable for demographic data in relation to both research subjects and the researchers themselves. To address internal issues, institutions can provide clear definitions of harassment and equip offices, such as offices of research or general council, to raise awareness of policies regarding reporting, investigations, and remediation of harassment claims. Some universities have implemented policies and provided resources to support researchers who are victims of doxing, or the publication of private or identifying information on the internet (e.g., Columbia University's Resources to Assist Ater Online Targeting/Doxing,[8] University of Illinois Urbana-Champaign's Trolling and Doxxing Attacks on Scholars – Executive Officer Action[9]). Professional societies like the American Association for University Professors have also issued guidance for faculty members who have been targeted by online harassment.[10] Notably, some of the forementioned resources for addressing online harassment may only be effective for addressing internal threats, and external threats may need to be addressed differently.

Advanced data security measures and data use can be resource-intensive, requiring modern infrastructure and sophisticated hardware or software that may not be accessible in underresourced schools, small community hospitals, low-income areas, or partners from low- and middle-income countries (Onoja & Ajala, 2022). This digital divide can prevent individuals in these areas from accessing secure services, thereby secure, yet affordable, technology solutions are essential to bridge this gap.

By addressing the specific barriers that data security can present, institutions can create a more secure, equitable, and inclusive digital environment. Effective data policies may include:

- Designing with accessibility in mind, ensuring that security measures do not hinder usability for people with disabilities.
- Investing in technology that is accessible and affordable.
- Adapting security measures to diverse cultural and linguistic contexts to ensure broad usability and understanding.
- Actively working to eliminate biases in security technologies to ensure fairness and equity.
- Enhancing privacy protections to build trust among marginalized populations.
- Involving diverse groups in the policymaking and governance processes concerning data security to ensure that these measures are equitable and inclusive.

[8] See https://universitylife.columbia.edu/doxing-resources

[9] See https://provost.illinois.edu/faculty-affairs/faculty-resources/trolling-attacks-on-scholars-executive-officer-action/

[10] See https://www.aaup.org/issues/targeted-harassment/what-you-can-do-about-targeted-online-harassment

Physical Security

Implementing physical security policies and protocols is also critical to protecting the safety of team members. Security risks can extend beyond threats to personnel to also include damage to physical spaces, equipment, and information technology systems. Institutions participating in team science, as well as science teams themselves, could benefit from being aware of and prepared for potential security issues that can arise, particularly when their research focuses on unpopular, politicized, or controversial topics. For example, some scientists working on projects related to COVID-19 have faced harassment and instances of physical violence (National Academies of Sciences, Engineering, and Medicine, 2023; Nogrady, 2021). Additionally, researchers who work with animal subjects have long been the target of extreme attacks, including bombings and arson (Collier, 2014). Along with the risks to the physical security of researchers, researchers who work on sensitive topics or are the targets of perceived or actual threats may also have additional needs to maintain psychological safety (Paterson et al., 1999; Williamson & Burns, 2014).

The National Research Council has previously issued guidance that research institutions and science teams can use to protect their physical safety (National Research Council, 2011). For institutions, this can include the use of security systems and the control of access to facilities, including through locks and access cards. Science teams can encourage individual members to increase their situational awareness and report suspicious behavior. They can also provide all members with training on what to do if a security emergency arises and avenues for reporting any incidents. Additionally, teams may need to take care in sharing scientific results when there are concerns regarding content and venue (Beechey, 2024). Teams can create dissemination and communications plans and data management plans to safely share results, which may include actions such as avoiding social media and anonymizing data.

Institutions have also issued crisis toolkits to provide resources to targeted individuals. For example, the University of Massachusetts Amherst's Academic Freedom Crisis Toolkit provides resources and outlines the responsibilities of both faculty and administrators in responding to a security crisis.[11] This stresses that the onus of responsibility lies not only with faculty and team members, but also with the institutions.

Finally, it is important to note that security can pose a particular challenge for team science, as science teams can include community members who may not have access to or knowledge of institutional resources. Multi-institutional teams can also face challenges with differences in institutional

[11] See https://www.umass.edu/faculty-development/resources/academic-freedom-crisis-toolkit

practices and protocols, making team communication at the outset of projects important in deciding what practices and protocols will be used and creating a cohesive strategy for how the team will respond to security issues.

Adapt to Changing Configurations

Importantly, virtual, hybrid, and in-person teams rarely remain in the same configuration over time. For instance, a group initially composed of principal investigators at the same university might expand to include international researchers or transition from mostly in-person meetings to fully remote interactions. As teams evolve over time, it is necessary for the ways technological tools are used to also evolve to accommodate new needs and challenges. As team compositions and structures change, the affordances of technological tools (e.g., video conferencing software, shared databases, project management platforms) may need to be revisited. *Affordances* refers to the potential actions or functions that a tool offers based on how it is used (e.g., Gibson et al., 2022). For instance, a team may have decided initially to use a tool for ad hoc communication but subsequently realized a need for handling more complex coordination tasks, such as scheduling across time zones or managing larger datasets.

As team configurations evolve, it becomes essential to revisit the accessibility norms and expectations that were initially set for the use of these technologies. A tool that worked well for a small, collocated group may no longer be effective for a dispersed or growing team. Similarly, accessibility needs may shift as team members from different regions or with different technological proficiencies join. Regularly reviewing these norms and conducting additional training when necessary ensures that all team members remain on the same page and can fully leverage the tools at their disposal.

Best Practice: Team Leadership

Leadership has been a major focus of research in the organizational sciences for the past century (Carton, 2022; Yammarino et al., 2005; Yukl et al., 2002). However, empirical research on leadership in science teams specifically is relatively limited. Therefore, this section draws primarily from the broader leadership literature, especially the literature on team leadership (e.g., Zaccaro et al., 2001), to discuss leadership for science teams. When applicable, we incorporate findings from studies of science team leadership. The committee emphasizes the need for further research investigating science team leadership, particularly research focused on how to develop and support science team leaders.

Leadership is broadly defined as "the process of influencing others to understand and agree about what needs to be done and how to do it, and the process of facilitating individual and collective efforts to accomplish shared objectives" (Yukl, 2006, p. 8). Whether this influence process emerges and proves effective depends on multiple factors, including the characteristics of leaders and followers and their interactions, as well as situational elements such as timing, group history, goals, and the scope of leadership activities (e.g., within a single team vs. across multiple interdependent teams). Moreover, leadership in science teams might be exerted by people who occupy formal positions of authority (e.g., principal investigators) or informally, by people without official leader positions. Leadership in science teams is often shared, distributed, or rotated over time, particularly when teams are large and include multiple co–principal investigators.

Team leadership can be understood through the lens of functional leadership theory, which argues that leadership effectiveness is the extent to which leaders and leadership processes support team effectiveness (Zaccaro et al., 2001). Team effectiveness is multifaceted and includes (a) *team dynamics*, or how effectively team processes and emergent states contribute to performance while fostering team learning and future collaborations; (b) the degree to which the team's performance outputs meet or exceed performance expectations; and (c) the extent to which individual members benefit personally from being part of the team (see also Chapter 5). Thus, effective leadership in science teams refers to how well leaders and leadership processes support these core aspects of science team effectiveness. Notably, it is important to consider team leadership as a dynamic process that plays a critical role throughout the team life cycle. While the team performs activities related to achieving its goals, leaders can perform functions such as managing team boundaries, challenging the team, and providing resources (Morgeson et al., 2010).

Effective team leaders prioritize supporting team dynamics (Zaccaro et al., 2001). To do so, leaders can use the best practices discussed in this chapter to establish key enabling conditions for team effectiveness (Hackman, 2012): a real team, a compelling purpose, the right people, clear norms of conduct, a supportive organizational environment, and positive leadership styles such as coaching.

The first enabling condition, a real team, is an intact social system with clear boundaries that distinguish members from nonmembers. Team members work interdependently toward shared goals, with collective accountability for outcomes. Science team leaders can use tools such as team charters, team debriefs, and team communication, and they can clarify team membership and patterns of interdependence.

The second condition is a compelling purpose that inspires and intellectually simulates the team. A well-defined purpose can motivate team members, align their efforts, and engage their talents. Establishing a clear purpose early on is crucial, as it influences team structure and determines the necessary organizational support. Science team leaders could articulate and reinforce a compelling purpose during initial team-building activities and throughout all phases of the team's life cycle.

Third, leaders need to ensure the team is made up of the right people. This means carefully selecting members based on their skills and suitability for collaboration and ensuring that team members sufficiently understand one another's areas of expertise. To this end, leaders could leverage best practices related to team assembly and carefully consider aspects of team composition.

Fourth, leaders can establish and reinforce clear norms of conduct through regular communication, meetings, feedback, and debriefs. Setting clear behavioral expectations minimizes the need for managing team member behavior and allows the team to focus on performance. These norms also encourage continuous evaluation of the team's environment and the adoption of appropriate strategies. Leaders who articulate high-performance goals, provide constructive feedback, and model effective strategies help support the team's affective and motivational states, such as trust, cohesion, psychological safety, and collective efficacy. Furthermore, leaders maintain the emotional climate by keeping conflicts task-focused and managing stress during high-pressure situations. Leaders also guide team coordination processes, ensuring that actions and resources are synchronized. For example, leaders can facilitate the integration of individual contributions and establish communication norms that foster flexibility and adaptability in dynamic environments.

Fifth, leaders can help ensure that the team has necessary resources and that the organizational environment remains supportive of team activities by engaging in boundary-spanning activities with the external environment. Boundary-spanning activities might include securing resources and information, building external relationships, advocating for the team, transferring knowledge, or coordinating with other teams (Marrone, 2010; Marrone et al., 2007). As articulated in Chapter 4, support from the broader scientific ecosystem can be essential for team science success.

Lastly, effective leaders provide team coaching and adopt positive leadership styles, such as transformational leadership (Hall et al., 2018) and inclusive leadership. *Transformational leadership*, characterized by communicating an inspiring vision, encoring innovation, and promoting personal and collective growth, has been linked to enhanced team performance and creativity (Bass, 1999; Schaubroeck et al., 2007; Wang et al., 2011). Inclusive leadership behaviors including taking time to learn about and act upon the strengths, needs, and preferences of each member of the team; inviting different points of views on a topic; and practicing humility and limiting power dynamics, such as through shared leadership and decision-making (Nishii & Leroy, 2022; Roberson & Perry, 2021; Shore &

Chung, 2021). Inclusive leadership promotes psychological safety, which in turn leads to greater risk-taking and innovation (Brasier et al., 2023b). Team coaching, particularly when conducted by formal leaders, can have a positive effect on team processes and performance (Bisbey et al., 2021b; Shuffler et al., 2018; Traylor et al, 2020). Coaching behaviors can evolve as the team progresses, shifting from inspiring vision during development to offering moral support, problem-solving, or coordinating resources during implementation (Hackman & Wageman, 2005; Reich et al., 2009).

In conclusion, effective leadership is crucial for the success of science teams, particularly in fostering team dynamics and ensuring the achievement of shared goals. According to the broader literature on team leadership, science team leaders need to strive to create the enabling conditions necessary for team effectiveness. This involves establishing a real team with a compelling goal, assembling the right mix of team members, setting and reinforcing behavioral norms, and maintaining a supportive emotional climate. This also involves engaging in boundary-spanning activities (e.g., securing resources, aligning the team with the external environment) and exhibiting positive leadership behavioral styles (e.g., transformational and inclusive leadership, team coaching). These leadership practices are important throughout the life cycle of the team. Given the unique demands of science teams, future research on effective leadership in science teams will be essential for improving their collaborative efforts.

FUTURE RESEARCH QUESTIONS

This chapter has outlined best practices for supporting science teams, situating them within the framework of the four stages of transdisciplinary research (Hall et al., 2012) and highlighting cross-cutting practices. Although the best practices discussed in this chapter are widely recognized as important for enhancing team science effectiveness, the committee emphasizes several key caveats. First, not all best practices will be suitable for every team or scenario. Science teams are variable in their structures, composition, and purposes—ranging from small, focused groups working on narrow and specialized problems to large cross-disciplinary teams tackling broad, complex issues. Moreover, the ideal timing and implementation of a best practice can vary depending on many factors, including team size, purpose, goals, challenges, or level of virtuality. It is important for teams to carefully assess their unique context and needs to determine which practices will be most beneficial and when they need to be applied.

The committee's second key caveat is that the empirical evidence base for team science best practices is still evolving. Although the broader literature on teamwork has identified key strategies that science team leaders, facilitators, or members could apply to enhance team effectiveness, the specific application of these practices in science teams requires further investigation. Some of the best practices discussed in this chapter, such as team charters and team debriefs, are well established and supported by a strong empirical foundation (e.g., Courtright et al., 2017; Mathieu & Rapp, 2009), whereas other best practices are based on the committee's expert judgment. When possible, the committee recommends best practices with empirical evidence. However, when this evidence does not exist, the committee recommends best practices based on committee and other expert experience. Moreover, with regard to the best practices with a stronger empirical foundation, much of the research has been conducted in organizational contexts outside of scientific collaboration. Since science teams share many essential characteristics with teams outside of science, the best practices identified in the broader literature on team effectiveness are likely to be relevant within the context of team science. However, science teams may also exhibit unique characteristics that are relatively underexplored in the broader literature on team effectiveness. To the extent that science teams differ from other types of teams, some best practices drawn from the general teamwork literature may not be fully applicable. This creates an evidence gap specific to team science that highlights the need for further research on team science best practices and development of tailored approaches for optimizing science teams.

The critical research questions in Table 3-1 are intended to encourage research on the best practices discussed in this chapter. Although not exhaustive, these questions provide researchers with a foundation for exploring unanswered areas within the science of team science. Table 3-2 presents a summary of the best practices described in this chapter, for easy reference.

TABLE 3-1 Research Questions for Understanding Effective Science Teams

	Research Questions
Development	
Team assembly	What are the most important characteristics (beyond expertise) for selecting science team members to maximize collaboration and scientific output? How do team members' orientations toward teamwork and interdisciplinary science influence the development of attitudes (e.g., trust, cohesion) in newly formed science teams? How do structured onboarding processes (e.g., tailored team charters, mentorship programs) affect team science attitudes (e.g., psychological safety), behaviors (e.g., communication across disciplines), cognition (e.g., knowledge integration, role clarity, shared mental models), and productivity? Do these vary by experience or seniority (e.g., new graduate students, postdoctoral researchers) within established science teams?
Team onboarding and building	How do onboarding practices contribute to fostering a sense of belonging and engagement among members of science teams? How do belonging, engagement, and psychological safety affect team processes and outcomes? At what stage in the team's developmental life cycle do team-building activities contribute most to the success of science team success? How do nontask team-building activities (e.g., social events such as meals) affect team processes and outcomes? How do task-based team-building activities (e.g., writing retreats) or team-based initiatives (e.g., conflict resolution workshops) affect team processes and outcomes? Of the above task and nontask team-building activities, how do they differentially influence emergent states such as psychological safety, trust, and cohesion within science teams?
Team charter	To what extent do onboarding strategies, such as the use of team charters, enhance alignment and mutual understanding during the initial stages of science team collaboration? Which components of a team charter (e.g., roles and responsibilities, communication protocols, conflict resolution, team goals) have the greatest impact on the long-term success of science teams? How does the inclusion of a detailed conflict resolution process in a team charter influence the ability of science teams to handle disagreements and maintain productivity?

TABLE 3-1 Continued

	Research Questions
Shared goals and understanding	What are the key factors that facilitate the development of shared mental models in newly formed science teams, and how do these factors vary across interdisciplinary and single-discipline teams? How do cognitive process interventions (e.g., systems mapping, boundary objects) affect knowledge and behavioral coordination? How does the process of collaborative goal formulation and the negotiation of task interdependence during the early stages of team formation contribute to the emergence of shared mental models? How does the frequency and quality of team communication influence the development of transactive memory systems in science teams? What are the challenges stemming from differences in expertise that prevent the science team from developing shared cognitive states (e.g., shared mental models, transactive memory systems)?
Conceptualization	
Team communication	How does the quality of team communication (e.g., clarity, openness, frequency) influence the effectiveness of scientific collaboration in interdisciplinary science teams? How do individual and organizational cultural and disciplinary differences affect communication patterns within interdisciplinary science teams, and what strategies are most effective in overcoming communication barriers? How does long-term communication scaffolding between senior and junior team members (e.g., graduate students, postdoctoral researchers) foster the development of expertise and support the gradual integration of new knowledge into the team's research output?
Project design	How does the use of boundary objects or physical artifacts influence knowledge coordination (e.g., integrative team planning, project design) in science teams? How does practicing epistemic humility among team members influence team processes (e.g., concept integration) and project outcomes (e.g., novel ideas) in interdisciplinary collaborations? What strategies are most effective in promoting even participation among team members in larger or heterogeneous science teams?
Implementation	
Team meetings	How does the frequency and structure of team meetings influence knowledge coordination (e.g., shared mental models) and behavioral coordination (e.g., participative decision-making) in science teams? How can team meetings best be leveraged to ensure that the methods and policies that set team norms and collaborative dynamics remain relevant as the team evolves? What meeting strategies (e.g., turn-taking) promote team learning and integration of different perspectives in science teams?

continued

TABLE 3-1 Continued

	Research Questions
Project management	Does real-time resource-sharing (e.g., data, software, documents) impact science team collaborative processes such that the team works better together and is more efficient in developing shared cognitive states (e.g., shared mental models)? What is the best strategy for employing regular team check-ins, where science team members discuss successes, failures, and unknowns, for virtual and hybrid teams to facilitate the development of team learning? What type of training is needed to facilitate the use of project management software in science teams to ensure that it is the most effective?
Team debriefs	How does the use of structured team debriefs impact the long-term performance and learning outcomes of science teams, particularly in high-complexity or interdisciplinary projects? What role does psychological safety play in enhancing the effectiveness of team debriefs in science teams, and how does it affect the willingness of members to share mistakes and areas for improvement? To what extent should text or video recordings be included in team debriefs and to what extent does their use enhance feedback accuracy and increase the acceptance of feedback among science team members?
Translation	
Open science	How does the implementation of open science practices (e.g., sharing data and methodologies) influence the speed and breadth of research translation into societal benefits? How does the use of open science practices foster interdisciplinary collaboration, and how does this collaboration contribute to more effective translation of research findings across different sectors?
Other	What strategies can science teams use to ensure that their findings are replicable and applicable across different societal, cultural, and geographic settings (i.e., external validity)? How does the focus on external validity during the research process impact the development of team dynamics and the eventual translation of scientific findings? At what stage is it best to include individuals directly impacted by the scientific research into the collaborative process to best facilitate the translation of findings? What communication strategies are most effective for ensuring scientific findings are understood and utilized by nonacademic partners, such as policymakers and community leaders? How does early planning for research translation influence the long-term success of translational efforts, and what are the key factors that contribute to effective planning across different phases of research? To what degree do translations goals need to be incorporated into ongoing team evaluations to best ensure that research findings are effectively moved into policy and practice?

TABLE 3-1 Continued

	Research Questions
Leadership	
Enabling conditions	How do science team leaders establish the enabling conditions for team effectiveness in a cross-disciplinary team context, and how quickly can these conditions be established? Can the responsibility for setting and reinforcing behavioral norms be distributed among all members of a science team, rather than resting solely on the formal leader, and can this shared responsibility be established immediately after team formation, or does it need to develop over time?
Boundary-spanning	Which boundary-spanning behaviors are most critical for team success throughout the scientific process, and does the importance of these behaviors change depending on the team's current scientific phase? To what extent will leaders engage in boundary-spanning activities to align team goals with the broader scientific ecosystem, and how transparent will they be with their team about these efforts?
Shared leadership	How does shared or distributed leadership influence team dynamics, accountability, and effectiveness in large science teams with multiple co–principal investigators? How does the rotating or shared leadership model in science teams affect leadership effectiveness, and what best practices can be developed to support this structure?
Collaborative Technologies	
Team configuration	How does the geographic distribution of science team members in hybrid and virtual science teams affect the use and effectiveness of virtual collaboration tools for sharing knowledge-related research materials? To what degree are cultural and language-based barriers to scientific collaborations in international science teams mitigated when using technological tools?
Technology–team interaction	What impact does exposure to and familiarity with virtual collaboration tools have on reducing anxiety and enhancing productivity in interdisciplinary scientific collaborations? To what degree does establishing norms for using virtual collaboration tools influence the quality of communication, engagement in effective team processes, and development of important emergent states in hybrid and virtual science teams?
Tool accessibility	How does the accessibility of virtual collaboration tools, particularly for scientists with disabilities, affect their participation and contribution to team science projects? What are the potential risks of data breaches or violations of privacy when science teams use virtual collaboration tools, and how can these risks be mitigated?
Adapting to changing configurations	What critical events determine when the use of technological tools needs to be revisited (e.g., adding new team members, changes in geographic distribution)?

TABLE 3-2 Summary of Best Practices for Science Teams

	Best Practice
Development	
Team assembly	• Conduct a team task analysis to determine what is needed for the project, including team size and needed knowledge, skills, and abilities • Consider team composition, including teamwork and taskwork competencies of team members • Recruit team members by articulating a compelling vision for the project
Team onboarding and building	• Onboard in ways that increase both work-related and personal familiarity • Design team-building activities that focus on goal-setting, interpersonal relationships, role clarification, and/or problem-solving
Developing a shared language	• Ensure all team members have a clear understanding of how terminology will be used, particularly when terminology is used differently in different disciplines • Use modes of communication that are accessible to all team members
Conceptualization	
Team charters	• Use team charters to clarify team planning aspects such as goals, processes, roles, and timelines • Include all team members in the development process of a team charter • Treat team charters as living documents that require periodic review and revision
Team planning and project design	• Frame team planning interventions as problem-solving • Use boundary objects to support team understanding of a problem • Promote open dialogue and the consideration of different perspectives during planning • Allocate sufficient time to planning
Implementation	
Project management	• Maximize the effectiveness of meetings by having a clear agenda, being mindful of time, and creating an environment where participants feel psychologically safe • Use facilitators to optimize team meetings • Foster structured dialogue between team members (e.g., implementing turn-taking during meetings) • Make use of existing project management platforms and programs
Team debriefs	• Periodically review and reflect on team performance and progress, including a discussion of both aspects that are going well and those that are going poorly
Translation	
Connecting with community members	• Establish clear communication with community member partners on research aspects including roles and responsibilities

TABLE 3-2 Continued

	Best Practice
Cross-Cutting	
Technology	• Consider team configuration and how that may evolve when assessing virtual collaboration tools • Ensure that technological tools align well with team member skills, needs, and comfort levels • Select tools that are accessible to all team members, considering their individual and differing needs • Establish clear expectations around use of technological tools • Carefully craft data security and use protocols that consider aspects including accessibility • Revisit technology norms and expectations periodically as teams evolve
Team leadership	• Prioritize supporting team dynamics by establishing key enabling conditions for team effectiveness • Provide team coaching and positive leadership styles • Exercise inclusive leadership and limit power dynamics by practicing shared leadership

CONCLUSION AND RECOMMENDATION

Conclusion 3-1: The following strategies offer the potential to improve science team performance and outcomes, if adapted to specific contexts and circumstances.

- *Development stage: careful team assembly that reflects a task analysis, consideration of the team composition, attention to the orientation of new members, and development of a shared language.*
- *Conceptualization stage: development of a team charter, deliberative team planning and project design, and attention to a shared mental model of the team's work.*
- *Implementation stage: systematic project management, regular team debriefs to identify what went well and what went poorly at each stage and to determine the best ways for the next project stage.*
- *Translation stage: working with community members and attention to external as well as internal validity, that is, understanding of the generalizability of the research findings.*

Recommendation 3-1: Research funders, including the National Science Foundation, the National Institutes of Health, and the many other agencies and foundations that support research, should provide resources enabling the study of team development, conceptualization, implementation, and translation.

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Institutional and External Supports for Team Science

When scientists share their experiences about working in teams, they frequently refer to ways that their working environment hinders teamwork. Complaints range from the trivial—the difficulties of adding an external collaborator to a messaging system—to the existential—the bureaucratic obstacles involved in sending funds or data to collaborators at other institutions (e.g., Byers-Heinlein et al., 2020). Principal investigators also point to structures that disincentivize participation in large projects because of the emphasis placed on first- or final-author publications rather than contributions to manuscripts with many authors (e.g., Forscher et al., 2023). Members of science teams often worry that their collaborative work will not be acknowledged during their institutional tenure and promotion processes or that their work may be less likely to find a "home" in the most prestigious journals of their field (Forscher et al., 2023).

These concerns highlight that team science takes place in an overlapping set of contexts that together are important determinants of success or failure. These contexts include the institutions—academic and nonacademic—in which research takes place and their infrastructure and policies. They also include funding for team science and policies associated with specific funders. Finally, they include the scientific culture as a whole and scientific incentives that motivate research, including intersections with journals and scientific societies. Each of these contexts includes qualities that can help or hinder teams. Therefore, to best answer the question in the statement of task pertaining to best practices, the committee elected to include best practices and potential gaps that are external to the team or are situated at the institutional level. Specifically, this chapter draws from the literature to cover institutional infrastructure, culture and policy, funders, and scientific incentives.

INSTITUTIONAL INFRASTRUCTURE

Because most researchers work within institutions (academic or nonacademic), they rely on these institutions to provide infrastructure to support their work. This infrastructure can range from the basic (e.g., space, connectivity, administrative support) to the highly specialized (e.g., research computing support). As researchers collaborate in larger teams that cross traditional boundaries—including laboratory groups, disciplines, and institutions—or teams that span sectors, the friction caused by infrastructural barriers (or the lack of support by a home institution) can hinder progress substantially (Forscher et al., 2023; Mirel & Harris, 2015). In this section, the committee highlights the roles that institutions play in providing physical infrastructure; technological resources, defined broadly as software, data storage, and computation; and human resources, including personnel and project management support for teams. Critically, through legislation such as the Americans with Disabilities Act (2010), institutions are required to make reasonable accommodations for individuals with disabilities.

Physical Infrastructure

Physical environments can manifest a critical barrier for individuals with disabilities on teams (e.g., Lindsay & Fuentes, 2022). Despite advancements in accessibility regulations and standards, many scientific institutions and workplaces still lag in providing fully accessible physical spaces and equipment (Jeannis et al., 2020). For example, scientific laboratories are often designed without consideration for individuals with physical disabilities—for example, laboratory benches and equipment may be positioned at heights that are unreachable for scientists who use wheelchairs (Heidari, 1996; Hilliard et al., 2013). In addition, narrow or unclear aisles and nonadjustable furniture can further limit accessibility (Jeannis et al., 2020). The inaccessibility of research tools and equipment can also limit full participation in scientific research teams (Devitz, 2023). Inaccessible tools not only limit inclusivity within labs but also can prevent researchers from engaging in field research and participating fully in the workplace.

Making accessible practices systematic rather than ad hoc is crucial (Americans with Disabilities Act, 2010). For disabled scientists, this means creating an environment where their participation is seamlessly integrated into all aspects of team operations (Anderson et al., 2022; Persson et al., 2015). Most importantly, these practices can be proactive rather than reactive (Mamboleo et al., 2020). Instead of waiting for a team member to request disability access needs or raise concerns, teams can anticipate and plan for their specific needs from the start. For example, laboratories or institutions might restructure their lab protocols to be inherently accessible by creating protocols that can be executed effectively regardless of whether someone is standing, sitting, or using assistive devices (e.g., Burgstahler, 2012). Ensuring that lab spaces are designed with adjustable workstations, sufficient maneuvering space, and accessible equipment is crucial for enabling disabled scientists to conduct their research independently (e.g., Massachusetts Institute of Technology, n.d.).

One method for addressing the need for accessible tools and the associated costs, which can often be an insurmountable barrier even when the need is recognized, is to establish an equipment repository (Devitz, 2023). The National Science Foundation (NSF) has also provided funding through Facilitation Awards for Scientists and Engineers with Disabilities to support the engagement of researchers with disabilities.[1] Furthermore, a survey by the Job Accommodation Network (2023) found that many workplace accommodations were low cost.

Conference rooms and collaborative spaces can also overlook the needs of disabled individuals. Accessible meeting spaces ought to include features such as ramps or elevators, wide doorways, adequate lighting, and seating arrangements that cater to individuals with mobility impairments (Americans with Disabilities Act, 2010; Smith & Dropkin, 2018). Furthermore, the availability of assistive technologies, such as hearing loops and accessible presentation equipment, can enhance these spaces significantly (National Institute on Deafness and Other Communication Disorders, 2019). Solutions such as using a live interpreter rather than closed captioning when possible can optimize the effectiveness of accessibility solutions. Beyond laboratories and meeting rooms, public areas such as restrooms, cafeterias, and communal spaces also need to comply with accessibility standards (Americans with Disabilities Act, 2010). Inaccessible amenities can severely affect the overall experience and daily functioning of disabled researchers, thus indirectly affecting their productivity and sense of belonging within the team (Lindsay & Fuentes, 2022).

Notably, by using universal design principles, creating accessible environments benefits all team members, regardless of ability. Universal design principles include providing all users the same provisions, creating designs

[1] For more information about the NSF Facilitation Awards for Scientists and Engineers with Disabilities, please see https://www.nsf.gov/funding/opportunities/dcl-persons-disabilities-stem-engagement-access-pwd-sea

that are flexible in nature, making designs easy to use and understand, and ensuring that designs are usable with little physical effort for all users.[2]

Technological Resources

Technological resources necessary to perform team science include software, data storage, and computational resources. Choices around these resources are critical enablers of progress in team science. Too often, teams take a piecemeal approach to information management, resulting in conflict that hinders their progress (Kelly et al., 2023). Furthermore, in the case of data sharing—or even sharing materials such as presentations—funders may make specific mandates regarding whether and how sharing proceeds; for example, they may regulate sharing based on specific regulations such as the Defense Federal Acquisition Regulation Supplement (2020) or export controls.

Collaboration Software

As teams grow larger and more distributed across time, space, and sector, the need for collaboration, communication, and project management tools increases dramatically (see Chapter 3). Practically speaking, these tools are instantiated in commercial or open-source software products (de Vreede et al., 2016). Open-source tools are freely accessible to all collaborators. While many commercial tools, such as word processing software and conference and chat platforms (e.g., Google Docs, Zoom, Slack, or Microsoft Teams), offer free versions, they are often limited in functionality and may not meet the needs of larger projects. As a result, institutions typically purchase the full versions of these tools. Site licenses for these products can be very helpful for facilitating intra-institutional collaboration—for example, by setting up shared messaging platforms or by sharing documents through institutional storage. But they can also be extremely restrictive. For example, if a cross-institution team, such as those across academia and industry, would like to set up a message board, they may not be able to—even if many or all researchers have access individually to the appropriate software (e.g., Microsoft Teams, 2025). When faced with this challenge, teams have the option to either use free versions of proprietary software or operate outside their institutions' recommendations to reduce collaboration barriers.

The challenge of proprietary collaboration software can be addressed by both institutional and community solutions. Institutions can recognize the

[2] To learn more about universal design, see the Centre for Excellence in Universal Design at https://universaldesign.ie/

need for teams to access shared software platforms and allocate resources to support collaborative access, by, for example, providing guest access to important collaboration platforms (e.g., Emerson College, 2025). Alternatively, teams can consider using exclusively free and open-source software for collaboration. While many of these tools (e.g., the open-source version control package "Git") are extremely powerful, they require substantial training to use, especially for scientists who do not have formal education in software engineering (Braga et al., 2023; Perez-Riverol et al., 2016). Indeed, recognizing this need, organizations such as The Carpentries[3] train scientists in the basic open-source tools that power software engineering (Wilson, 2013).

Relatedly, one barrier to effective participation in team science can include the lack of accessible communication (Isaacson et al., 2011; Persson et al., 2015; Rizzo et al., 2024). This includes issues with verbal and written communication, as well as the use of digital tools and platforms. For example, individuals who are D/deaf or hard of hearing often face significant challenges in environments where verbal communication predominates (Adler, 2025; Gehret et al., 2017; Marchetti et al., 2024). Written materials, such as research papers, meeting agendas, and collaborative documents, may not always be available in formats that are accessible to individuals with learning disabilities or who are blind or have low vision. For instance, scientific documents that are incompatible with screen readers or lack alternative text for images and graphs can prevent individuals from fully understanding and contributing to the material (Kumar & Wang, 2024; Singh Chawla, 2024). In addition, the increasing reliance on digital communication tools for virtual and hybrid meetings may pose further accessibility challenges (Bercaru & Popescu, 2024). Platforms that do not comply with accessibility standards can be difficult or impossible for some individuals to navigate. Features such as screen reader compatibility, keyboard shortcuts, and adaptable text sizes can help make these tools accessible to all users. Furthermore, including options for text-to-speech and speech-to-text capabilities can accommodate various disabilities in real-time communication tools, such as chat functions (Bercaru & Popescu, 2024).

Data Storage

Increasingly, science is data intensive (Kitchin, 2014), and many teams require data storage and sharing infrastructure. At smaller scales, these needs can be met by user- and enterprise-focused commercial platforms, such as Dropbox or Google Drive (with all the licensing challenges described above). At larger scales and for more complex datasets, bespoke solutions are often required.

[3] More information about The Carpentries is available at https://carpentries.org

In the best-case scenario, datasets are unencumbered by legal or ethical restrictions and can be shared openly. For example, when datasets (as well as working documents, protocols, and materials) are shared in open repositories, it is far easier for collaborators to access them across a wide range of platforms and geographic locations (Baumgartner et al., 2023). This greater accessibility through openness highlights the importance of open science practices in facilitating collaboration (see Box 4-1). Data can be shared

BOX 4-1
The Role of Open Science in Facilitating Team Science

Open science describes a broad range of practices and policies emerging from the central role of transparency in scientific progress (Crüwell et al., 2019; Klein et al., 2018; Spellman et al., 2018). Open-science practices can include sharing code and data (when permissible based on privacy and other constraints), preregistration of hypotheses, distribution of scholarship through posting preprints, and open-access publication. These practices together are intended to increase the reproducibility, replicability, and rigor of research by providing all the materials necessary for independent researchers to verify published research. They also aim to increase the impact of research by broadening the set of research products that can be reused (Piwowar & Vision, 2013; Wilkinson et al., 2016). Finally, they are intended to decrease barriers to inclusion in science by ensuring that anyone can engage with scientific products, regardless of background or affiliation (Grahe et al., 2020).

Although it is not always possible to do so, making data, analysis, and administrative documents (including team charters [see Chapter 3]) open dramatically decreases barriers for joining teams (Dai et al., 2018). Especially when teams have a "grassroots" strategy, open materials can encourage engagement from researchers, including those from nonacademic backgrounds (Baumgartner et al., 2023). Furthermore, openness around scientific products can signal a science team's interest in broad engagement.

Open-science tools and approaches can vastly simplify team operations, especially when they span institutions and countries. Tools for data and materials sharing—especially in the context of institutionally licensed products—can require complex and cumbersome security measures. These measures are warranted when there are regulatory or legal constraints on data sharing. In the absence of such constraints, however, making research materials open can be the easiest way to ensure that all team members can access them (Foster & Deardorff, 2017). For example, the Open Science Framework (OSF)[a] is a software platform for sharing and managing research products and facilitating open collaboration across science teams. Unlike commercial file-sharing platforms, research materials shared through the OSF receive digital object identifiers and are guaranteed to be accessible in perpetuity (Alter & Gonzalez, 2018).

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[a] More information about the Open Science Framework is available at http://osf.io

through institutional repositories such as Dataverse; cross-institutional platforms such as Zenodo, Figshare, Data Dryad, the Open Science Framework and others; and field- or dataset-specific repositories (e.g., OpenNeuro,[4] a free and open database of brain imaging data).

Challenges multiply, however, when teams deal with datasets that are encumbered by legal or ethical restrictions—as is often the case for data from human participants in the social and biomedical sciences. For example, the overlapping regulatory constraints on sharing data from clinical trials are complex (Gudi et al., 2022). In their study of translational teams, Kelly et al. (2023) highlighted how the complex security requirements for data sharing hindered their attempts to translate research findings between university collaborators and clinical or community partners. This research demonstrates how complications may be amplified when attempting to streamline coordination of team members across sectors.

Ensuring that stored data and information are accessible is also important. For example, scientific information, whether in the form of research papers, datasets, or educational resources, can be available in accessible formats (e.g., Rizzo et al., 2024; Wu et al., 2022). This includes providing documents that are compatible with screen readers, offering braille versions, and utilizing large print formats. Utilizing plain language summaries can also enhance understanding for individuals with cognitive or learning disabilities. Visual data representations, such as charts, graphs, and infographics, play a significant role in scientific research. However, these visual tools can be challenging for individuals who are blind or have low vision. Providing alternative text descriptions, tactile graphics, and audio explanations can help make this information accessible (e.g., Vidal-Verdú et al., 2007).

Online platforms and repositories where scientific knowledge are shared also need to adhere to web accessibility standards. This includes ensuring that websites are navigable via keyboard, providing text alternatives for multimedia content, and ensuring that interactive elements are accessible. In addition, enabling customizable viewing options can help individuals tailor their browsing experience to suit their specific needs. Mandates exist, such as Section 508 of the Rehabilitation Act (29 U.S.C. § 794d; General Services Administration, 2024). This is a federal law that requires agencies to provide individuals with disabilities equal access to electronic information and data comparable with those who do not have disabilities, unless an undue burden would be imposed on the agency. However, while compliance with standards such as Section 508 is necessary, it is merely the starting point for creating inclusive environments. Current standards can sometimes fall short of being accessible (Pearson & Alexander, 2020). Institutions can aspire to

[4] More information about OpenNeuro is available at https://openneuro.org

go beyond compliance, adopting a proactive stance toward inclusion and equity where access is seamlessly integrated and viewed as essential, not burdensome (Humphrey et al., 2020; McDaniels & Asiedu, 2023).

Computational Resources

With the rise of artificial intelligence (AI) and machine learning methods, team science projects increasingly require high-performance computing resources, including access to clusters of graphics processing units (GPUs) or other specialized hardware (e.g., Besiroglu et al., 2024; Fujinuma et al., 2022; Ho et al., 2022; Puertas-Martín et al., 2020). There are current worries about the scarcity of access to GPUs (Griffith, 2023), which could decrease innovation in universities (Ho et al., 2022). For example, availability of computational resources has been cited as a major reason why industry is taking a larger role in recent research on AI (Ahmed et al., 2023). Thus, institutional access to high-performance computing resources enables science teams to thrive (Apon et al., 2010; Vecchiola et al., 2009). In the context of cross-institutional or cross-sector teams, the ability of collaborators to offer computational resources can also be an important incentive for collaboration.

Human Resources

As teams grow larger and more complex, the human resources required to ensure their success have increased significantly. Reimagining who is considered a member of the science team and establishing appropriate funding mechanisms can help foster more inclusive and innovative research (National Science Foundation, 2023; Specht & Crowston, 2022). Much of the diversity surrounding scientists can be found in the adjacent ecosystems, including staff members, study participants, and community partners (Bergeron, 2021; Passmore et al., 2022; Swartz et al., 2019). This extends beyond simply adding more personnel; specialized expertise is needed for developing and managing team science initiatives, particularly those spanning multiple disciplines or institutions. As team science projects increasingly cross disciplines, institutions, sectors, states, and countries, grant proposals for these projects have become more challenging to prepare initially and implement successfully after receiving funding. Institutions play an important role in human resources for team science, as they can provide training in team science skills and access to designated research personnel, including individuals with skills ranging from proposal development to financial administration and compliance. Historically, NSF responded to this challenge with its Growing Research Access for Nationally Transformative Equity and Diversity (GRANTED) program[5] in 2023, which focused on bolstering the support ecosystem. In this context, the following sections review evidence for the role institutional personnel play in enhancing team science. Most of the works discussed are theoretical, anecdotal, or case based; more robust empirical investigations are needed.

Research Development Professionals

Research development professionals represent a relatively new but rapidly expanding profession with potential for advancing team science (Carter et al., 2019; Chedin, 2024; Hunt, 2019; Preuss et al., 2018). In the view of the National Organization of Research Development Professionals (NORDP, n.d.), *research development* "encompasses a set of strategic, catalytic, and capacity-building activities that advance research, especially in higher education" (p. 1). Research development grew out of research administration, coinciding with more competitive funding environments and additionally the rise of higher-dollar, longer-term team science opportunities from major funders that placed new demands on research ecosystem personnel to actively and intentionally support budding science teams (Levin, 2011; Mason & Learned, 2006; Mulfinger et al., 2016). As discussed in Chapter 3, most factors that influence team science success fall outside technical, disciplinary areas that comprise the bulk of scientists' training and expertise—that is, outside task competence. Building on this history, NORDP's (n.d.) four research development pillars are:

1. enhancement of collaboration and team science,
2. strategic research advancement,
3. communication of research and research opportunities, and
4. proposal development.

Given its relative newness, the role of research development professionals is evolving in the university ecosystem. The exact roles they play depend on their placement within an institution, including whether they are located within a central office or spread across smaller units, such as colleges, medical schools, and research centers. Overall, though, research development professionals' contributions can cut across all four of the NORDP components. For example, they may deliver grant training that can lead to more collaborative proposals; convene research groups and networking opportunities that can build cross-disciplinary, cross-sector, and cross-institutional bridges; disseminate funding opportunities that can initiate a

[5] More information about the GRANTED program is available at https://new.nsf.gov/funding/initiatives/broadening-participation/granted

team effort; and provide extensive proposal development and interpersonal coaching that can produce more competitive funding proposals, including for large research centers. For institutions that offer internal team science seed-funding opportunities, it is common for research development professionals to lead or otherwise facilitate these programs. For example, Stanford University's Research Development Office (2024) is staffed by a group of research development professionals with experience in team science.

Survey data collected from NORDP members showed that research development professionals view "proposal development support for large, multi-investigator project grants" as their most important activity, outranking "grant team project management (coordination of meetings, proposal development deadlines, shared documents, etc.)" (Ross et al., 2019, p. 118). Stephens et al. (2024) were the first to empirically (albeit retrospectively) test what were previously only descriptive linkages between the support of research development professionals and funding outcomes. In the context of a U.S. medical school, they found that coaching in teamwork provided by research development professionals is positively associated with an awarded outcome, with notable gains for new teams and those with both research and clinical responsibilities (Stephens et al., 2024), suggesting the value these professionals can add for teams when familiarity and bandwidth among team members are low. A related, yet distinct area of potential support for a team includes funding for Research Specialist Awards, such as those offered by the National Cancer Institute (NCI). Similar to research development professionals, these awards are designed to support the research with personnel who do not serve as independent investigators (National Cancer Institute, 2024).

Research Administrators

While research development professionals support the formation, ideation, resource acquisition, and proposal development of science teams, *research administrators* support team science from a distinct yet equally important lens of compliance, monitoring, reporting, and financial support services (National Council of University Research Administrators, n.d.). Research administrators can be in a main sponsored programs office or distributed across an institution. They are well positioned to mitigate documented scientific costs of multi-institutional collaborations (e.g., Cummings & Kiesler, 2007), including helping teams spend less time and attention navigating institutional differences in appointment structures, salary payments, and policies.

Additionally, anecdotal evidence suggests that research administrators can be essential when science teams partner with other community members or organizations outside academia. Even when sponsors such as the National Institutes of Health (NIH) encourage a community-engaged approach, specific guidance around how to fund such engagement in team science can be sparse. Moreover, the proposal guidelines and policies that do exist are designed for use by academic actors (Seidel, 2022). Research administrators can bridge this gap between funders, science teams, and community partners by helping to administer subawards or subcontracts to community partner organizations and by ensuring necessary assurances, certifications, and protections are in place. From a fiscal standpoint, and relevant to the following discussion of nonscientist collaborators, research administrators can also bridge compliance gaps between a funder's allowable costs and a community partner's budgetary and compensatory needs, which may look different from what is traditionally found in a research proposal budget and for which no standard rates apply (Seidel, 2022).

Facilitators and Integration Experts

Scholars increasingly call for greater recognition of and support for specialized professionals who operate at the nexus of research, relationships, and operations to help teams navigate the inherent challenges of collaboration and maximize potential benefits (e.g., Barker Scott & Manning, 2024). The specific roles and terms used to describe them (e.g., interdisciplinary executive scientist, facilitator, integration expert, coach) may differ, but there is significant conceptual similarity among them.

Hendren & Ku (2019) identified the role of *interdisciplinary executive scientist* as one who coordinates and connects into an integrated whole the scientific, administrative, and interpersonal pieces of a science team. These professionals, they argue, operate within the liminal spaces between roles and disciplines to actively ensure desired outcomes, such as synthesis and translation, are achieved rather than simply assuming they will emerge (Hendren & Ku, 2019).

Duke University's Clinical and Translational Science Institute (CTSI), funded in part by NIH, instituted the similar role of project leader after recognizing that asking principal investigators to lead the project, team, and science efforts at once is unrealistic and unsustainable, especially if their training has been only scientific (Sutton et al., 2019). As an extension of the principal investigator, CTSI project leaders pair their scientific understanding with team science best practices and tools, including team charters and project development plans, to achieve collaborative goals (Sutton et al., 2019). Vogel et al. (2021) described how the Division of Preclinical Innovation within NIH's National Center for Advancing Translational Sciences has institutionalized roles to support its large, heterogeneous science teams as well. These roles include, for example, project analysts, who track team activities and schedule meetings, and project managers, who take leadership roles in scientific discussions and mitigating conflict.

Another role in team studies is that of *facilitator*, or one who supports collaboration for research teams, with a key distinction being how external they are to the team (see Widdowson et al., 2020). Facilitators might be engaged to oversee discussions (Clutterbuck, 2007) or manage the collaborative process (Hawkins, 2018), while not necessarily being part of the team. In recent years, the role of facilitator has been tailored for science teams and established as a semiformal position within a team. This role is typically filled by someone skilled in scientific collaboration practices who might also possess interactional expertise (Cravens et al., 2022). *Interactional expertise* involves a certain understanding of scientific tasks, enabling the facilitator to communicate relevant scientific practices (Bammer et al., 2020; Collins & Evans, 2019). However, others suggest that science facilitation may focus simply on tasks such as organizing scientists and their meetings or coordinating projects (Jiang et al., 2023).

A closely related but more specialized role is that of an *integration expert*, whose focus is on helping scientists combine knowledge across various disciplines. Hoffmann et al. (2022) described integration experts as scholars who "lead, administer, manage, monitor, assess, accompany, and/or advise others" (p. 3) during interdisciplinary teamwork. This can also involve some form of coaching.

Although the roles described here are defined by different competencies, there is overlap; facilitation, integration, and coaching frequently intersect in these discussions. For instance, Cravens et al. (2022) mentioned that cofacilitators can act as coaches to support reflective learning, while Hoffmann et al. (2022) highlighted *advising* as a competency for integration experts, which they define as including "accompanying, supporting, or coaching others" in leading integrative efforts and achieving integrated outcomes (p. 3). As another example, several scholars have highlighted how facilitation is key for guiding effective team processes, designing productive interactions, fostering communication, promoting participatory decision-making processes, and encouraging knowledge exchange (Cravens et al., 2022; Graef et al., 2021; Kaner, 2014).

A substantial issue requiring more study is the fact that professionals inhabiting such roles are most often tied to temporary project funding. Since many science teams begin as unfunded collaborations or use institutional seed funding, support for these roles may not be available. Furthermore, even when personnel with expertise relevant to team science are engaged, they are more likely to be misunderstood, overlooked, and undervalued because of their boundary-spanning position (Bammer et al., 2020; Hendren & Ku, 2019; Hoffmann et al., 2022; Lyall, 2019). As a result, sustainable, long-term investments in personnel are needed as critical team science infrastructure (Hendren & Ku, 2019; Hoffmann et al., 2022; Rolland et al., 2017).

Regardless of whether individuals are engaging in unfunded, institutionally funded, or sponsored research, the personnel discussed in this section are critical to making teams work and achieving their scientific goals. Much about this process remains understudied, however. As discussed, if the members of a science team are broadened to include research development professionals who are involved in the conception, development, implementation, and dissemination of team science inputs, processes, and outcomes, institutions may be able to better develop metrics to help assess the efficacy of these roles in contributing to team science. Importantly, measuring efficacy can be done at multiple levels, from surveying team members to assessing their connection to broader team science metrics (see Chapter 5). Periodic assessments can inform continuous improvement of individuals, their roles, or departmental processes, and can quantify and characterize how research development personnel, or related professionals, contribute to team science outcomes at their institutions (Bennett & Gladin, 2012). For example, there is little research on which project management tools, models, or frameworks are being adopted by individuals within these roles and whether these approaches address the administrative, coordinative, and generative workload that can accompany team science (e.g., innovation and project management research [Davies et al., 2018]).

Other Nonscientist Team Members

Several applied science fields offer approaches and frameworks that more directly address including nonscientist team members as part of the science team. These include community-based participatory research (CBPR) and human factors or ergonomics (HFE) science, in part because their research objectives often cannot be achieved without input from nonscientist team members (Giardullo, 2023; McDermott, 2022). Whereas CBPR grew out of health research domains (Leung et al., 2004) and HFE from addressing human–technology performance concerns during World War II (Meister, 1999), both fields are concerned with improving systems and testing interventions. In CBRP and HFE, success is measured by the actual adoption of the intervention, not just a demonstration in a laboratory that it works. Thus, for both CBPR and HFE, it is practically impossible to achieve their research objectives without including nonscientist teammates as study participants or localized subject matter experts and community partners, who may play a critical role as recruiters, maintainers, improvers, problem definers, problem solvers, and implementers of parts of a project that are necessary to realize the project’s scientific or research objectives (Gopalan et al., 2020).

While including nonscientists as team members may not be as critical for all scientific fields, it is increasingly important for scientists and researchers aiming to tackle complex problems that may require complex solutions. The effective and ethical implementation and adoption of AI in society is one example of a complex societal problem that will increasingly need to involve marginalized communities that have been traditionally excluded from AI research and development teams (Parthasarathy & Katzman, 2024). Agricultural development research (Ingram, 2014) and sustainability (Diaz-Reviriego et al., 2019; Ernst et al., 2017; Osinski, 2021) also frequently involve and rely on people who are not career scientists in their research work and knowledge implementation. In general, these subject matter experts comprise the very population that the researchers are intending to help (Smikowski, 2009; World Health Organization, 2023). Scholars have discussed the importance of not only involving nonscientist team members but also implementing routine practices that foster trusting relationships. This can include the ethical and safety considerations of data sharing practices for example, with those who have historically not been on science teams (Kraft & Mittendorf, 2024; Sabatello et al., 2022).

INSTITUTIONAL CULTURE AND POLICY

Institutional policies and informal cultures can support and motivate team science; alternatively, they can create barriers that stifle scientific collaboration and the production of interdisciplinary research. To support team science, institutions can carefully consider the nature of their policies and cultures and, as needed, revise policies to streamline collaboration and encourage and reward teamwork (National Research Council, 2015). For example, hiring, tenure, promotion, and other reward systems (e.g., internal institutional awards, small grants) may need to be revised to reward team science. Policies related to materials and data sharing, ethical approvals, and staffing support may need to be revised to reduce unnecessary barriers to team science. This section will consider the impact of institutional policies and cultural features on scientific collaboration and suggest strategies for creating institutional environments that are conducive for team science.

Material Transfers, Data Sharing, and Intellectual Property Policies and Procedures

Policies related to materials and data sharing are often cited as significant barriers to team science (Borgman, 2012; Kowalczyk & Shankar, 2011). Indeed, because science teams are more likely to need to share materials and data, they are more likely to need to work with personnel who have expertise in these policies (e.g., research administrators, other team science–related personnel). One hurdle for research teams is the complexities involved in negotiating material transfer agreements and data use agreements, which may deter researchers from sharing valuable resources (Mello et al., 2020). These agreements are designed to protect intellectual property and ensure ethical use of materials and data, but they can become overly burdensome and time consuming. Challenges related to these agreements can be overcome through the open release of data and materials in cases where no privacy or intellectual property constraints exist (see Box 4-1). When such concerns exist, however, institutional policies can be a determinant of whether sharing is possible (Bubela et al., 2015).

Barriers to Collaboration

A primary challenge for team science related to material transfer and data use agreements is the intricate legal and administrative processes they often entail (Mello et al., 2020). These agreements are often reviewed extensively by legal departments, which can lead to prolonged negotiations. Researchers often navigate multiple layers of approval, from their home institution to the receiving institution, each with its own set of requirements and protocols. This bureaucratic maze can result in significant delays, sometimes stretching into months, thus stalling scientific progress (Bubela et al., 2015; Mello et al., 2020).

The lack of standardized templates and procedures for material transfer and data use agreements across institutions further complicates the process. Each institution may have its own unique agreement terms and conditions, leading to a situation where each new collaboration necessitates the drafting of a bespoke agreement. This lack of uniformity not only increases the time required to finalize agreements but also may add to the costs involved (Mello et al., 2020). Institutions and researchers may find themselves in prolonged negotiations over specific terms, such as intellectual property rights, confidentiality clauses, and usage limitations.

Although the protection of intellectual property is a legitimate concern, the stringent terms often embedded in material transfer and data use agreements can be counterproductive (Bubela et al., 2015). For example, clauses that limit the sharing of derivative works or impose strict usage restrictions can inhibit the free flow of information and resources necessary for collaborative research. Researchers might hesitate to share their materials or data, fearing that they may lose control over their intellectual contributions or that their work might be misappropriated.

Similar barriers exist in collaborations among industry, academia, and/or national laboratories, where intellectual property and publication terms are agreed upon in advance of any collaboration. In such arrangements, industry benefits from expanding their capabilities and subject matter expertise to answer fundamental research questions that may be beyond the scope of what their organization is able to address alone, and academia benefits from additional funding sources, direct access to industrially relevant research challenges, and expanded networks for students who may be interested in a career in industry following their academic studies (Chai & Shih, 2016; Stuart & Ding, 2006).

Impact on Collaboration

In combination, complex legal and administrative processes, a lack of standardization, and stringent limitations on the sharing of intellectual property can be a significant deterrent to team science collaboration (Mello et al., 2020). Researchers, especially those studying time-sensitive topics in fields such as medicine or environmental science, may opt to work independently rather than engage in the cumbersome process of securing material transfer and data use agreements. This fragmentation of effort can lead to duplicated work, inefficiencies, and a slower pace of scientific advancement (Bubela et al., 2015).

In the field of biomedical research, for example, sharing biological samples, such as cell lines, tissues, and genetic material, is critical. However, the negotiation of transfer agreements for these materials can be particularly arduous. For example, a researcher attempting to obtain a unique cell line from another institution might face months of negotiations over the terms of use, publication rights, and potential commercial applications. This delay can hinder timely research advancements and potentially delay the development of new therapies or diagnostic tools.

Similarly, environmental scientists often rely on data collected from different geographical locations and multiple research teams. The negotiation of data use agreements for accessing these datasets can be fraught with challenges. Institutions may have different data protection policies, leading to lengthy negotiations. For instance, a researcher seeking to combine climate data from different sources to study global patterns may face significant delays due to the need to secure multiple data use agreements, each with specific requirements and restrictions.

Potential Solutions

One effective strategy for mitigating these barriers is the standardization of material transfer and data use agreements (Bubela et al., 2015). Developing common templates that are accepted across institutions can streamline the negotiation process. Federal funding organizations can spearhead efforts to create standardized agreements that balance the need for intellectual property protection with the facilitation of scientific collaboration (e.g., Bennett et al., 2010). Furthermore, it may be worth exploring whether having specialized teams that understand the intricacies of these agreements can expedite the review and approval process (Steiner et al., 2023).

Creating clear and flexible guidelines for the use of materials and data can also help. Institutions can provide researchers with frameworks that outline the necessary ethical considerations without imposing overly stringent requirements. Providing researchers with training and resources to understand and comply with these guidelines can further reduce the compliance burden. Often teams can pursue an "open by design" strategy to foresee and avoid complex regulatory situations (National Academies, 2018). Institutions and funding agencies can also create incentives for sharing materials and data, by, for example, recognizing such sharing in their metrics for research products. U.S. federal funders now require data sharing (Nelson, 2022), and grant proposals could be evaluated favorably if they include proactive plans for both scientific data sharing and public-facing dissemination. Recognizing and rewarding researchers who contribute to shared resources can also foster a culture of openness and collaboration (Nosek et al., 2015; Shaw et al., 2022). Lastly, advanced technologies can provide solutions for some of these challenges. Online platforms that facilitate the sharing of materials and data, equipped with built-in compliance and tracking features, may have the potential to streamline these processes (Wegner et al., 2024).

In conclusion, although policies related to materials and data sharing are essential for protecting intellectual property and ensuring ethical research practices, they can become significant barriers to team science if not managed effectively. The complexities and time-consuming nature of negotiating material transfer and data use agreements can deter researchers from engaging in collaborative efforts, thereby slowing scientific progress and innovation. By pursuing open-science policies when possible, standardizing agreements, providing centralized legal support, creating clear guidelines, offering incentives, and leveraging technology, institutions can reduce these barriers and promote a more collaborative and productive research environment.

Ethical Approvals

For research involving human participants, ethical approval from institutional review boards (IRBs) is one of the most important—and sometimes one of the most challenging—administrative tasks (Oakes, 2002). This generalization can often be especially true for practitioners of team science, for whom the challenge of obtaining ethics approval in a single discipline and institution is multiplied by navigating multiple IRBs across institutions (McWilliams et al., 2003; Peek et al., 2021). Furthermore, this situation can result in substantial variation in ethics review outcomes, which means that participants may be protected to greater or lesser degrees depending on the vagaries of local review (Caulfield et al., 2011). This situation has improved in recent years but can remain challenging in the context of international or non-university collaborators.

Prior to 2018, researchers engaged in cross-institutional research were typically required to pursue independent review by local IRBs. This situation required substantial duplication of effort and could easily lead to difficult situations in which different IRBs required conflicting alterations to a protocol. NIH addressed this issue in 2018 by revising the Common Rule to require a single IRB to be designated as the primary site for review of multisite projects involving human participants (U.S. Department of Health and Human Services, 2018). IRBs for other participating institutions are required to create a reliance agreement with the primary IRB. These agreements substantially decrease the burden of review by independent sites but still require a significant investment of resources by participating investigators (Resnik et al., 2018). Evidence from a similar policy instituted earlier by NCI indicates that a single-IRB process led to substantially more efficient review and higher satisfaction for investigators (Massett et al., 2018). Consistent with this evidence, a qualitative study of single-IRBs in clinical trials regulated by the Food and Drug Administration showed generally high satisfaction with the process (Corneli et al., 2021). Unfortunately, single-IRB policies driven by the Common Rule do not apply to international research with human participants; hence, multisite international collaborations can remain quite challenging from the perspective of ethical approvals.

Hiring, Tenure, Promotion, and Reward Policies and Procedures

Historically, academic success has been measured by individual achievements such as the number of first-authored publications, personal citation counts, and individual grant awards. These criteria are often used in hiring, tenure, and promotion decisions to assess a candidate's contributions and impact within their field. Although these metrics can provide a quantifiable measure of an individual's academic performance, hiring, tenure, and promotion policies and procedures that focus exclusively on these metrics can disincentivize collaborative efforts (Bouwma-Gearhart et al., 2021). Indeed, the focus on individual achievements can create a competitive environment where researchers are less likely to engage in team science (National Academies, 2020). Collaborative projects, which often involve shared credit and coauthorship, may be viewed as less valuable during tenure and promotion evaluations. As a result, researchers might avoid interdisciplinary collaborations and/or team-based research out of fear that their contributions will not be recognized nor rewarded. To foster a culture of team science, universities may need to revise these policies to encourage and reward collaboration (Klein & Falk-Krzesinski, 2017).

Hiring Practices

University hiring policies and procedures can support interdisciplinary collaboration by emphasizing the value of differing expertise and teamwork in the recruitment process. For example, job descriptions could explicitly state the importance of interdisciplinary research and collaborative skills, ensuring that candidates understand the institution's commitment to team science. Hiring committees can be composed of members from various disciplines to evaluate applicants' potential for cross-disciplinary work effectively. Additionally, universities can prioritize candidates with a proven track record of successful collaborations, assessing their ability to integrate different perspectives and contribute to multifaceted projects (Klein & Falk-Krzesinski, 2017). Joint appointments across departments or faculties, for instance through interdisciplinary research centers, can further encourage interdisciplinary engagement by encouraging researchers to bridge gaps between fields and foster a culture of cooperation (Hart & Mars, 2008; Yang et al., 2020). Providing resources and support for collaborative research, such as funding for interdisciplinary projects and access to shared facilities, can also enhance the appeal of the institution to prospective hires. A useful tool to support collaboration across units is a memorandum of understanding (MOU). These can be established between participating units to ensure transparency. Like a team charter, MOUs can help establish a mutual understanding on roles and responsibilities and financial commitments. They can also specify the administrative contacts, level of expected effort, and the general scope of the work (Platt et al., 2024). Klein & Falk-Krzesinski (2017) added that MOUs not only define expectations but also can specify what is required for teaching and service across the participating departments, as well as percentages of time the employee dedicates to each. By integrating these elements into hiring policies and procedures, universities can create an environment that attracts and nurtures researchers committed to interdisciplinary collaboration.

From an industry perspective, having a proven track record of being able to successfully collaborate across teams in different institutions and geographies may provide candidates with an advantage over those with a more siloed research experience. Industry considers the ability to effectively collaborate across disciplines and business groups (e.g., supply chain, manufacturing, sales, marketing) as part of a baseline set of skills that is critical to success (Schwartz et al., 2019).

In March 2022, the U.S. House and Senate passed the America COMPETES (America Creating Opportunities to Meaningfully Promote

Excellence in Technology, Education, and Science) Act, which was a reauthorization of the COMPETES Act of 2007. The basis of this act was to enhance U.S. economic and technological leadership by investing in "innovation through research and development, and to improve the competitiveness of the United States" (America COMPETES Act, 2007). One key provision of the act called for investing in research and development that emphasized science, technology, engineering, mathematics, and medicine (STEMM) education and workforce development. The act acknowledges the need for a more representative workforce in STEMM fields and calls for measures to broaden participation.

Systemic barriers can be found in hiring, promotion, and recruitment practices, as well as resource allocation and power distribution (Bhalla, 2019; Li & Koedel, 2017; National Academies, 2023). These biases may undermine initiatives such as America COMPETES. For example, Milkman et al. (2015) found significant biases in professors' responses to prospective doctoral students, with fewer responses going to applicants who were women or from a minoritized group. The same study illustrated the need to not focus solely on one part of the barrier, but in the case of hiring and recruitment, that attention be given to both increasing individual differences on the supply side (e.g., by focusing on improving the heterogeneity of the applicant pool) and reducing bias on the demand side (e.g., by addressing personally held biases within the hiring and research context). Sege et al. (2015) summarized their preliminary findings in a research letter in which they found that female early career faculty received significantly less start-up support than their male counterparts. Nguyen et al. (2023) found disparities in super principal investigator representation across gender and racial lines, with significant gaps for women and Black researchers (*super principal investigator* was defined as investigators who hold three or more concurrently active research grants). Despite a threefold increase in super principal investigators between 1991 and 2020, women and Black super principal investigators remained significantly underrepresented, even after controlling for factors such as career stage and educational background (Nguyen et al., 2023). The intersection of race and gender creates compounded disadvantages, most notably for Black women principal investigators, who were 71 percent less likely to achieve super principal investigator status than White male principal investigators (Nguyen et al., 2023). This stark disparity suggests that systemic barriers go beyond applicant pool issues and points to deeper institutional challenges in advancement opportunities, mentoring systems, resource allocation, and institutional support for underrepresented scientists. As a result, long-standing gender imbalances can create additional challenges for women and racially minoritized individuals seeking to advance in their careers (Casad et al., 2021; Charlesworth & Banaji, 2019; National Academies, 2023).

Tenure and Promotion

Tenure and promotion policies and procedures can significantly support team science by recognizing and rewarding collaborative efforts alongside individual achievements (Carter et al., 2021). Promotion and tenure systems are often criticized for their lack of transparency and potential biases. Traditional metrics for evaluation, such as publication count, journal impact factors, and grant money, may inadvertently disadvantage certain groups of individuals, such as women (Misra et al., 2011). To foster a culture of interdisciplinary collaboration, universities could revise evaluation criteria to include contributions to team-based research projects, coauthored publications, and collaborative grant awards (Klein & Falk-Krzesinski, 2017; Meurer et al., 2023) and provide clarity for the evaluators and investigators on the criteria (Potter et al., 2024). For example, Meurer et al. (2023) outlined criteria that can be used to evaluate how well a faculty member helps with team effectiveness (e.g., "develop consensus around shared research goals," "provide participatory, inclusive, and empowering leadership" [p. 4]), as well as how they contribute to the scientific process (e.g., assist in developing research questions, engage in data analyses and interpretation). Klein & Falk-Krzesinski (2017) further noted that existing policy documents related to tenure and promotion need to be evaluated to ensure they do not penalize or marginalize interdisciplinarity and team science. As such, evaluation criteria would consider investigators who may contribute a high level of expertise in a methodological or theoretical approach (e.g., qualitative/quantitative methods or community engagement), who are sought out as collaborators on multiple projects and grants for their unique skills and may or may not have their own line of research. Metrics can be expanded to assess the impact and quality of collaborative work, rather than focusing solely on the quantity of solo-authored outputs (Meurer et al., 2023). Allowing tenure and promotion candidates to submit narrative statements that detail their role in team science, the significance of their collaborative contributions, and the outcomes of such efforts can provide a more comprehensive evaluation of their achievements. Additionally, recognizing leadership roles within collaborative projects, such as coordinating research teams or managing interdisciplinary initiatives, can highlight the importance of teamwork in achieving significant scientific advancements. By incorporating these elements into tenure and promotion criteria, universities can incentivize researchers to engage in team science, ultimately enhancing the institution's research capabilities and addressing complex, multifaceted problems through a collaborative approach. For example, the University of Southern California (2022) policy on promotion and tenure provides explicit guidelines on the use of external letters and the candidate's research statement to clarify unique contributions to team science.

Academic departments can inadvertently create barriers to team science based on the journals they privilege for recognition and reward. When departments exclusively reward publications in disciplinary journals, they often send a message that only research contributions within that single discipline are valuable for their employees to pursue (Mäkinen et al., 2024). These metrics can discourage constituent scientists from pursuing interdisciplinary collaborations and/or publishing in journals that reach broader audiences, as these endeavors may be seen as less prestigious or beneficial for career advancement. On the other hand, departments have the potential to foster collaboration and interdisciplinary research by rewarding publications based on their overall quality, regardless of the specific journal (Frank, 2019). By recognizing and valuing publications across a range of disciplines, departments can encourage scientists to engage in team science, share knowledge across fields, and contribute to more comprehensive and innovative research. This approach not only supports the career growth of individual researchers but also has the potential to enhance the overall quality and societal impact of the scientific work produced (Arnold et al., 2021; Carter et al., 2021; Mazumdar et al., 2015; Moher et al., 2018).

To value and support team science, tenure and promotion policies and procedures may need to be expanded to include collaborative leadership, interdisciplinary contributions, and the effective management of research teams. This may mean recognizing the critical roles that researchers play in team-based projects, from coordinating large, multifaceted studies to facilitating communication and cooperation among team members. It also may mean recognizing the longer timescale of many team science projects (Hall et al., 2012). Incorporating diversity into the promotion and tenure criteria can incentivize faculty to engage in activities that promote values such as mentoring diverse students or leading community-based projects (Stewart & Valian, 2018). This also recognizes and gives credit for the valuable mentoring and community-engaged work (Sotto-Santiago et al., 2023). This multifaceted approach could be considered more akin to how industry treats promotions, where promotions are generally based on technical, business, and organizational impact, all of which may require strong collaboration skills, interpersonal effectiveness, and teamwork.

Additionally, tenure committees could understand and appreciate the unique dynamics of team science, which often involve substantial time investments in team formation, coordination, and ongoing communication (Klein & Falk-Krzesinski, 2017). Revising tenure criteria to reflect these aspects can help institutions foster a culture that not only incentivizes but also rewards collective scientific efforts. By doing so, they can promote an environment where collaborative research is valued, leading to greater scientific innovation and impact. This approach not only benefits individual researchers by recognizing their contributions to team efforts but also can advance the institution's overall research mission by encouraging interdisciplinary and high-impact projects.

FUNDERS

Major funders of research within the United States and globally have long understood the value of team science for addressing priority challenges and accelerating innovation. For instance, NSF funded the National Socio-Environmental Synthesis Center (SESYNC)[6] in 2011 as a first-of-its kind center focused on growing researchers' team science capacities to address interdisciplinary problems collaboratively at the interface of humans and the environment. As another example, the NIH National Institute on Minority Health and Health Disparities (2024) launched the Transdisciplinary Collaborative Centers for Health Disparities Research Program in 2012 to support "collaboration at the regional level [...] because it provides opportunities for institutions and organizations to achieve a broader reach than is possible with isolated local efforts while combining expertise and resources in an era of constrained budgets" (Section I).

As described in Chapter 2, interest in funding team science since the publication of the 2015 report has continued (National Research Council, 2015). In 2017, NSF amplified its support of team science by prioritizing foundation-wide investments in cross-disciplinary collaboration and creative cross-sectoral partnerships, establishing "Growing Convergence Research" as one of its 10 Big Ideas.[7] Also important to consider is whether funding agencies' signaled interests in and support for team science efforts align with other aspects of the research funding landscape, such as proposal solicitations and review and project funding.

Proposal Solicitations and Review

How funders solicit and review research proposals, including funding opportunity language and requirements, can have implications for team science effectiveness. For example, NSF's (2024) call for Science and Technology Centers (STCs) allows for the inclusion of team science–related requirements at all levels, including in the proposal content (e.g., "Highlight the unique assets and strengths, including the diversity of experiences and perspectives, of the proposing team compared to other groups working in related areas" and "Identify specific activities and mechanisms that will enable cross-organizational and cross-sector integration of the team") (p. 11)

[6] More information about SESYNC is available at https://www.sesync.org

[7] More information about NSF's 10 Big Ideas is available at https://www.nsf.gov/news/special_reports/big_ideas/index.jsp

and solicitation-specific review criteria (e.g., "Is the team of partner organizations and personnel assembled for the proposed Center appropriate, essential and consistent with the solicitation? Is the role of each participant clear? Does the partnership have unique strengths?") (p. 20).[8]

NSF's Engineering Research Center (ERC) program has prioritized team science in its solicitations. For example, in 2018, for applicants who made it past the preproposal stage for ERCs, NSF funded attendance at a team science workshop led by SESYNC, which featured sessions and talks led by team science experts from across the country with goals of elevating and strengthening team science in ERC proposals. Actions taken by programs such as the STC and ERC encourage proposal teams to factor team science principles and best practices into their project design (and budget) from inception; they also allow NSF as the funder to weigh team science–specific concerns in its decision-making processes.

The degree to which the STC and ERC calls explicitly prioritize and integrate team science is not typical of proposal solicitations from funding agencies; however, more subtle proposal requirements, resources, and policies can still influence team science outcomes. For example, NIH allows for a multiple principal investigator option on grant applications. This option requires that applicants include a leadership plan that addresses the responsibilities of each principal investigator, as well as publication policies and procedures for resolving conflicts.[9] To aid in plan development, the National Center for Advancing Translational Sciences offers agreement templates and discussion questions[10] to guide collaborators (see also the discussion on team charters in Chapter 3). Similarly, at NSF, team proposals are increasingly required to develop a collaboration plan that reflects on the rationale for the collaboration while detailing team plans for communication, governance, integration, project management, and more (e.g., see NSF I-Corps Teams[11]). NSF's invitation to submit collaborative proposals, where multiple institutions submit as equal partners, may additionally spur more productive collaborations as this option can save both time and money by eliminating subawards and equalizing power dynamics between collaborating entities.

Although some aspects of the proposal development process have changed in recent years in response to the rise of team science, the committee discussed that the proposal review process has largely stayed the

[8] More information about the program solicitation is available at https://new.nsf.gov/funding/opportunities/science-technology-centers-integrative-partnerships/nsf24-594/solicitation

[9] For more information about NIH's option for multiple principal investigators, see https://grants.nih.gov/grants-process/plan-to-apply/consider-your-idea-resources-and-collaborators/multiple-principal-investigators

[10] See https://ncats.nih.gov/research/alliances/forms-and-model-agreements

[11] See https://www.nsf.gov/funding/initiatives/i-corps/about-teams

same. Some programs, such as the STC, have begun to include additional solicitation-specific review criteria and thus ask for evaluation of team science aspects of the proposed activities. Largely, however, proposals to major funding agencies are not assessed based on team science activities. If team science is not included in review criteria, investigators will not be incentivized to consider team planning and organization, in turn potentially decreasing the effectiveness of their teams.

Project Funding

Which proposals are funded, and how recipients are permitted to use those funds, can also have implications for team science. Support for team science training, for example, is most readily available in large center grants or training grants (e.g., National Institute of General Medical Sciences, 2025); however, team science approaches are important for teams and projects of all sizes (Hall et al., 2018). There is evidence showing that, compared with investigator-initiated research grants, NIH-funded transdisciplinary center grants faced an initial lag in productivity; however, they saw overall advantages for productivity and collaboration (Hall et al., 2012). The presence of such a lag suggests that the typical 3- to 5-year length of research awards may be too short to allow for proper planning, trust, relationships, shared vision, integration, dissemination or translation of project results, and other key aspects of team science to occur. Furthermore, planning grants, seed funding, travel for face-to-face meetings, and project coordinators can benefit science teams, yet such funding may not always be available or allowable. With the 26% federal cap on indirect administrative costs, which was implemented in 1991 (University of California, n.d.), budgetary restrictions on costs that are positively linked with team science outcomes means that award recipients may take on greater financial burdens to keep pace with the needs and costs of conducting team science effectively (Hall et al., 2018).

Beyond lack of support for team science components of funded proposals, a lack of funding for *research* on science teams is also problematic. More specifically, funding is lacking tremendously for those who want to study team science effectiveness. This creates a research-to-practice gap, in that the prevalence of science teamwork outpaces the ability to guide it. Research associated with science teams can often be viewed in a supporting or evaluative role rather than as a necessary research field in and of itself. As has been made clear throughout this report, however, there is a lack of strong evidence linking team science interventions or best practices to positive team science outcomes. With little funding made available for research on science teams, funding agencies may continue to rely upon guidance for funding and supporting science teams that is not fully informed by rigorous research (e.g., Berg, 2017; Kaiser, 2017).

Finally, funding agencies can directly or indirectly disincentivize team science through other policies as well. For example, tightening research security restrictions—such as the NIH (2023) laboratory notebook policy that requires foreign grant subrecipients to provide yearly copies of all lab notebooks and documentation to the primary grant recipient—can impose significant administrative burdens and potential privacy concerns that could dissuade international collaboration. As another example, programs supported by the 2018 Farm Bill limit total indirect costs for an entire award to 30%, meaning that all collaborating institutions would be in a position to recover costs from a single small pool of funds rather than independently at their federally negotiated indirect cost rate (U.S. Department of Agriculture, 2018). If collaborations cost institutions more than they benefit them, advances in team science are likely to stagnate.

SCIENTIFIC INCENTIVES

As discussed throughout this chapter, researchers are highly responsive to scientific incentives as imposed by institutions, funders, and their broader field. To the extent that these incentives reward team science, researchers will feel empowered to participate in team science; in cases where incentives are unfavorable, they may not be able to participate. This section discusses incentives that (dis-)incentivize contribution to team science.

Authorship, Contributorship, and Credit

Scientific publications serve as the primary currency in academia, where a researcher's career trajectory often hinges on the number of peer-reviewed articles listing them as an author. Scientometric indices, such as the h-index or the i10, index further quantify researchers' impact based on citation rates of their publications (Mingers & Leydesdorff, 2015). The importance of these authorship metrics in hiring, tenure, and grant decisions is well documented (e.g., see Moher et al., 2018, for a review). Yet these metrics do not reflect the reality that authors contribute in very different ways to projects. According to the International Committee of Medical Journal Editors (n.d.), listed authors are those who contributed to writing the paper and to the research being reported, approved the final manuscript, and agreed to be held accountable for the work; however, authorship standards vary widely across fields and even from journal to journal (Yale University, n.d.).

The authors on a paper are given as a list of names, but parsing out the contributions of each name is very difficult (e.g., Venkatraman, 2010). In standard biomedical authorship conventions, first authorship indicates primary responsibility for the scientific work described in the article (and, typically, true "authorship"—that is, having written the first draft of much or all the text of the article). In contrast, "senior" or last authorship typically indicates supervisory responsibility. For others, the order indicates significance of contributions. In fields following this convention, first-author positions are especially coveted, sometimes leading to the presence of "multiple first authors," as indicated by a note that several authors have contributed equally. In still other fields, such as economics, authorship order is typically alphabetical, and the assumption is that all authors made equal contributions. For external readers, especially those with limited knowledge of a particular field, it can be mystifying to decode the contributions of individual authors from the list.

Notions of authorship are even more challenging in team science (Coles et al., 2023). Increasingly, scientific papers have hundreds or even thousands of authors, a situation termed *hyperauthorship* (Cronin, 2001; Nogrady, 2023). One wonders how to apportion credit and responsibility among so many. In addition, the threshold for what constitutes authorship can be challenging to delineate within a science team when participants' contributions differ so widely. To address these issues, in 2015, the CRediT (Contributor Roles Taxonomy) introduced a taxonomy of contributions to scholarly work, ranging from conceptualization to funding acquisition (Brand et al., 2015). The intent of this taxonomy was to allow researchers to designate the role or roles that each contributor played in a project, obviating guesswork about how contributions were distributed across an author list. Since its introduction, a wide variety of journals have adopted CRediT (Allen et al., 2019), and in 2022, it was adopted as an American National Standards Institute (2022) standard (Z39.104-2022).

Another challenge for science teams is considering how team members can contribute to a multiauthor paper. Borer et al. (2023) provided a model for a collaborative process for writing papers with large numbers of authors, in which the lead author(s) establishes a "storyboard" for the paper and solicits specific and targeted contributions—for example, providing citations, creating figures, considering alternative hypotheses, and other moderately sized tasks—in an iterative, deadline-driven process. Frassl et al. (2018) provided a complementary set of rules for large teams to create a collaborative and productive writing process.

Synthesizing this set of issues, science teams navigating questions of authorship need to establish clear rules for what constitutes authorship, how to track the different kinds of contributions that authors may make to a project, and how to establish opportunities for team members to contribute to the written product (e.g., Baumgartner et al., 2023). Considerations for fairness and accountability should be made (International Committee of Medical Journal Editors, n.d.), to ensure that all participating authors such as those who are early career or nontraditional team members can be included. Returning to the guidance of Chapter 3, science teams could consider adopting such policies in their team charters.

Journals, Societies, and the Broader Field

Journals are the venues in which credit and authorship are determined, and their policies can provide powerful incentives and disincentives for team science. For example, a journal's requirement for individual author data to be entered into a web portal is not onerous for a small team, but for a team with hundreds or thousands of authors, this requirement can be prohibitive for submission. Allowing batch upload of name, affiliation, and Open Researcher and Contributor ID (ORCID) or other identifiers can make a journal accessible to larger teams. In addition, many journals ask for individual authors to provide explicit confirmation for submission (e.g., by way of email notification). This well-intentioned confirmation can inadvertently create a difficult situation for hyperauthored papers, in which a single contributor whose contact information changed can prevent a submission from going forward.

One potential solution for larger science teams is to pursue "group authorship" (also known as "consortium authorship"), where a single group name is given in place of a list of individual authors. This solution appears appealing but can have a variety of unintended consequences (Hosseini et al., 2024). Group authorship can pose technical challenges in associating the manuscript with the contributors' citation records, which can decrease incentives for contribution. In addition, issues of legal and ethical responsibility for the manuscript can be more problematic when individuals are not listed as authors (Hosseini et al., 2024). Thus, group authorship may not be a panacea; instead, journals ought to create policies that facilitate large teams in navigating the submission and publication process.

Scholarly societies provide another venue for recognition of scientific contributions, which can potentially facilitate team science. Many societies control important journals in their field and set their authorship policies. In addition, they often provide recognition of their members' accomplishments through awards. If these awards can be given to teams (e.g., as in the Society for the Improvement of Psychological Science Mission Award[12]) or to team leaders, this simple step can promote participation and change incentives for team participation.

Finally, embracing open-science values (Christensen et al., 2020; National Academies, 2018) can provide positive support for team science.

[12] More information about the the SIPS Mission Award is available at https://improvingpsych.org/mission/awards

Many large teams use open practices (see Box 4-1) and many teams also produce shared resources that benefit their field as a whole (Nogrady, 2023). Support—and recognition for the contributions of—open science can facilitate recognition of the many contributions that teams make beyond specific publications. Box 4-2 highlights a project that used open-science practices in a team science context to track research products and incentivize sharing of code, data, and materials.

BOX 4-2
Using Open Products and Resource-Tracking to Align Team Science Incentives

The Aligning Science Across Parkinson's (ASAP) initiative is an international, foundation-funded collective of researchers across institutions whose goal is to accelerate discoveries about Parkinson's disease. As part of this initiative, the group mandates compliance with a range of open-science policies, including posting of preprints, sharing of all research products (including materials, code, and data) to appropriate repositories, and using research identifiers such as digital object identifiers and research resource IDs for tracking contributions (Riley & Schekman, 2021). These practices facilitate collaboration within the network, ensure rapid dissemination of all products of network grants, and ensure that originators of the materials receive credit for their contributions.

Dumanis et al. (2023) described this move to open-science practices as initially challenging, in part because many investigators and trainees had limited education about how to curate and deposit research products. To facilitate compliance, they pursued a two-part approach. First, they used automated tools to track all manuscripts that were funded by the initiative and to identify whether resources were deposited and documented appropriately. By applying these tools before manuscripts were submitted, they were able to give feedback about what steps authors needed to take to achieve compliance with ASAP policies. Second, they developed training resources to ensure that participating laboratories had guidance in curating and depositing their research products.

Critically, these efforts have allowed for open data from funded Parkinson's investigators to be consolidated using team science approaches, accelerating discoveries about the disease while at the same time creating routes for individual investigators to receive credit (Junker et al., 2021). As this case study shows, open-science practices require support for science teams—through education and compliance tracking—but they can help to alleviate some of the disincentives for team science.

CONCLUSIONS AND RECOMMENDATIONS

Conclusion 4-1: Institutions wishing to foster the study of team science would benefit from reviewing the incentive structures that influence individuals' decisions about engaging in such research. Specifically, many policies and practices that are currently in place surrounding tenure and promotion, authorship, cost-sharing, allowable costs, and resource-sharing appear to discourage engagement in the study of team science and participation in collaborative science teams. Institutional processes can also reinforce disparities in team science by failing to properly recognize work in team science, including community-engaged research and mentorship.

Recommendation 4-1: Academic departments should adapt their promotion and tenure processes to acknowledge and reward the contributions of researchers who take on the additional professional responsibilities associated with participating in and studying team science by:

a. recognizing and incorporating in tenure evaluations the valuable contributions made through different authorship roles, publications in interdisciplinary or nontraditional journals, and process-oriented outcomes.

b. ensuring that the demographic and disciplinary composition of promotion and tenure committees is both reflective and independent of the candidates they are reviewing to the extent possible to facilitate increased representation in science team leadership.

c. revising criteria for selection to ensure fair consideration of candidates who research and team with underrepresented communities and/or do community-engaged research.

d. considering candidates' involvement in committees, initiatives, and other activities, including engagement outside the scientific community, that offer value to science teams and encourage participation.

e. reviewing the promotion and tenure process periodically, for instance every several years, to ensure continuous improvement and minimize inefficiencies.

Recommendation 4-2: Science journal editors should establish comprehensive systems and policies to build team science into the publishing mainstream, including:

a. conducting a systematic assessment to identify barriers that may limit the incorporation of team science literature in their journal. These findings should be used to develop actionable strategies to address identified barriers.

b. adopting clear policies and guidelines for authorship, allocation of credit, and contribution level, particularly when there are many contributing authors and when authors are contributing from different disciplines with different authorship practices. Policies can include strategies for addressing authorship disputes.

c. allocating appropriate space to publish research on the science of team science.

Recommendation 4-3: Funders of team science, including the National Science Foundation, the National Institutes of Health, and the many other agencies and foundations that support research, should integrate team science needs into funding programs and policies and should remove barriers to team science efficacy by:

a. including team science needs, such as team-building, travel and meetings, professional development and training, and resource-sharing in allowable costs.

b. allowing for the inclusion of nonscientist team members and leaders in the project budget to allow for the compensation of their time.

Recommendation 4-4: Institutions seeking to advance team science effectiveness should allocate resources to support science teams. Resource allocation may cover, but is not limited to the following:

a. resources that mitigate the operational burden on science teams by investing in the support of administrative staff.

b. training and mentorship for research administrative staff working on team science projects.

c. resources to expand access to and the use of technologies that optimize team participation for geographically dispersed members.

d. funding to address gaps in the physical, digital, and procedural environment. This could include applying universal design principles that accommodate the needs of all individuals.

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5

Evaluating Team Science

This chapter identifies key outcomes, methods, and measures for evaluating team science training and performance. The chapter uses the term *team science evaluation* broadly to refer to the systematic assessment of team-based scientific research efforts (Stokols et al., 2008). This process involves measuring and analyzing various aspects of how science teams function and collaborate, the outcomes they produce, and/or the broader impacts they achieve. Team science evaluation can help reveal the dynamics within a science team; assess the effectiveness of the team's collaboration processes; and determine how the team's work contributes to advancing scientific knowledge, achieving institutional objectives, and generating societal benefits.

Team science evaluation can refer to both traditional evaluation efforts, dictated by funders, and the measurement of team processes and outcomes as part of research investigating scientific collaboration. Based on the committee's literature searches, this chapter provides guidance for research evaluators in understanding which phenomena to assess when determining whether grant recipients are effectively meeting their funding objectives. It also guides scholars studying scientific collaboration with a broad understanding of the different constructs involved in team functioning—from inputs to processes to outcomes.

IMPORTANCE OF TEAM SCIENCE EVALUATION

The effectiveness of a science team can have far-reaching implications for a wide array of individuals and groups, all of whom have a vested interest in the team's success (Falk-Krzesinski et al., 2011). For example, the individual members of a science team—such as graduate students, postdoctoral researchers, faculty members, professional scientists, and administrators—are impacted directly by the team's functioning and effectiveness. There could be potential setbacks for an early career researcher if a dysfunctional team limits opportunities for publishing or networking. On the other hand, their professional growth, recognition, professional networks, and intellectual contributions could be enhanced through involvement in a productive science team. Additionally, the team can benefit as a whole from each member's contributions and collaborative processes. Successful team science collaboration can lead to groundbreaking research outputs and shared achievements (Thayer et al., 2018; Xu et al., 2022). Beyond the team, scientific institutions, such as universities and research centers, rely on the success of science teams to build reputations, secure funding, and fulfill their missions of advancing knowledge (e.g., Jones et al., 2008; National Science Foundation, n.d.). The impact of team science extends to an institution's ability to attract top-tier talent, secure multimillion-dollar grants (i.e., center grants), and maintain a leadership role in the advancement of knowledge. Entire scientific fields also stand to benefit from the efforts of science teams, driving innovation, expanding knowledge, and setting new standards within the discipline (Stokols et al., 2008). Society at large is another critical party interested in science teamwork, as the discoveries made by science teams could lead to technological advancements, informed public policies, solutions to pressing global issues, and ultimately improving quality of life and addressing societal needs (Stokols et al., 2008). The stakes can be high, such that, without effective team science, lifesaving discoveries or technological breakthroughs may remain out of reach.

Evaluating how science teams collaborate is vital for improving research partnerships across all science fields (Klein, 2008). Evaluation can help leaders and teams understand team dynamics, improve processes, adapt to challenges, manage risks, and foster inclusion and continuous improvement. Evaluating research outputs, such as publications, patents, and outreach efforts, can be vital for determining overall team effectiveness and highlighting the innovation and creativity fostered by team science. Evaluation can also help clarify the broader impacts of team science research, including societal, educational, and policy contributions, ensuring that wider goals are being met. This, in turn, can inform future resource allocation and funding decisions, ensuring the effective use of resources and justifying future investments. Moreover, evaluating teamwork processes, psychological states, and practices can help identify and refine best practices and successful strategies that could be shared and replicated across other team science initiatives (Klein, 2008; Stokols et al., 2008). Insights gained from team science evaluation may help lead to improvements in research methodologies, processes, and administrative support, thereby optimizing the overall effectiveness and efficiency of collaborative work (Belcher et al., 2015; Love et al., 2022; Roelofs et al., 2019). In short, systematic evaluation of team science can enable researchers, institutions, and funders to better support and enhance the contributions of collaborative research to scientific advancement and societal benefit.

CHALLENGES OF TEAM SCIENCE EVALUATION

Evaluating team science effectively is complex because of the need to address impacts on many types of groups, team dynamics, research types, research and organizational contexts, project time frames, and more.

The effectiveness of team science can impact different groups at multiple levels (e.g., individual, team, institutional, scientific, societal), so evaluation may need to consider the impact of team science across these different levels. For example, a thorough understanding of team functioning goes beyond team-level factors (e.g., team output and collaboration) to consider individual (e.g., attributes, contributions, individual outcomes) and contextual factors (e.g., institutional characteristics and outcomes) that both shape and are shaped by team dynamics. Thus, a key challenge for evaluators is identifying the most relevant factors at each level—individual, team, and context—to be included in the evaluation process.

The dynamics of science teams are complex, as teams may be composed of individuals with different goals, cultural contexts, and disciplinary areas. For example, team members may be dispersed geographically or have status differences within the team (e.g., junior faculty vs. senior faculty, medical researcher vs. community member). Some teams have fluid membership, in that members may join or leave the research over time. Thus, tailored evaluation methods are needed for capturing team interactions and outputs effectively.

Evaluations need to adapt to the type of work teams are pursuing. For instance, a team focused on biomedical research may have different collaborative dynamics, communication styles, and success metrics than a team working in environmental science. Teams conducting biomedical research may involve clinical (e.g., doctors, nurses) and laboratory researchers with different working schedules. Environmental science teams may conduct field studies and plan for long-term data collection efforts.

The cultural context, including the norms and values that guide behavior within the team, can also vary widely depending on the team's geographic location, institutional setting, and the professional or personal backgrounds of its members. Similarly, the disciplinary focus of a team influences the methodologies it uses; the nature of its research questions; and the types of outputs it generates, such as publications, patents, or policy recommendations. These complexities often necessitate flexible, context-specific approaches to team science evaluation that can accommodate the variable and evolving nature of team science endeavors (Hall et al., 2018; Stokols et al., 2003).

Team science evaluation can consider the timing of measurement as well as the evolution of team goals and dynamics over time (Mâsse et al., 2008; Stokols et al., 2008). Longitudinal data collection can be resource intensive, and teams often operate in different contexts, making it difficult to apply a standardized evaluation approach (Cummings et al., 2013; Hall et al., 2018; O'Connor et al., 2003). Identifying and consistently measuring relevant metrics that accurately reflect performance is another hurdle, as performance encompasses both outcomes and processes that can shift over time. Additionally, attributing changes in performance to specific factors is complicated by the influence of various internal and external variables (Ilgen et al., 2005). Temporal patterns and lag effects further complicate the assessment, as the impact of actions may not be immediately apparent (Ilgen et al., 2005). Furthermore, as team goals and success criteria often evolve throughout a project, evaluations may need to adapt to these changes.

The organizational context represents another key consideration when evaluating team science (Lee & Jabloner, 2017). For example, organizations outside of academia may have established training programs, best practices, and accountability and evaluation procedures (e.g., Barry et al., 2024; Savannah River Site, 2020) that can support team science. These practices often derive from hierarchical, command-and-control structures, yet productivity, cohesion, and retention within teams ultimately depend on the skills and behaviors of the direct leader and team members. Consequently, many industry organizations invest heavily in training employees in non-technical areas, such as project management, conflict resolution, positive leadership, and effective communication (Carucci, 2018; Day et al., 2021), all of which enhance collaboration and team science effectiveness (Delise et al., 2010).

Industry organizations frequently use anonymous employee surveys to gather feedback on what is working well and where improvements are needed, subsequently creating action plans to address identified gaps. Additionally, mechanisms for confidential peer feedback can contribute to continuous improvement by informing development plans. Regular performance discussions between employees and leaders provide ongoing real-time feedback that reinforces positive behaviors and allows leaders to address issues before they escalate. When more complex issues arise that team members cannot resolve themselves, experts from human resources and/or compliance and ethics departments can assist in investigating and mediating solutions. This emphasis on accountability can cultivate a culture in industry that supports team science. Although these systems are not flawless, they can establish a solid foundation for collaboration (Schneider et al., 1996). This feedback loop helps maintain productivity and ensures a positive return on investment.

However, since companies rarely share data on the outcomes linked to these practices, it is challenging to scientifically evaluate the strengths and weaknesses of various industry approaches to improving team science. In one exception, Google LLC has publicly shared the results of its internal research to understand what variables make some teams more successful than others, with a summary reported by Duhigg (2016) in *The New York Times*. Under Project Aristotle, researchers reviewed external literature and data from over a hundred teams throughout Google and found that psychological safety was the most important indicator for how a team would perform. High team psychological safety tended to track with equal speaking time and conversational turn-taking and high average social sensitivity (Duhigg, 2016). Although it is rare for companies to release such information externally, the results from Project Aristotle reinforce and are consistent with best practices for effective team science captured in the academic literature (e.g., Edmondson & Roloff, 2008).

In summary, the multifaceted nature of scientific ecosystems, the varied goals and strategies pursued by different science teams, the complexities of team dynamics over time, and the need to account for organizational practices and industry norms make it challenging to establish universal metrics or approaches for team science evaluation. The variable and evolving nature of science teams renders a one-size-fits-all approach to team evaluation inadequate. Instead, effective evaluation requires tailored methods for capturing the specific interactions, processes, and outcomes relevant to each team. This may involve adapting existing evaluation frameworks to align with a team's unique goals or developing entirely new metrics to accurately assess performance in context. As teams evolve—adapting to new challenges, incorporating new members, or shifting their research focus—the evaluation approach must also be flexible and adaptive to remain relevant and insightful, and to provide valuable feedback that guides the team's ongoing development and success.

A FRAMEWORK FOR GUIDING TEAM SCIENCE EVALUATION

Three overarching types of criteria could be considered when assessing the effectiveness of a work team (Hackman, 1987; Kozlowski & Ilgen, 2006). The first criterion, referred to in this chapter as *team dynamics*, assesses whether the team's social processes and emergent psychological states are effective and efficient in achieving the desired performance standards, while also fostering the team members' ability to learn and collaborate on future tasks. The second criterion assesses whether the teams' performance output meets or exceeds the performance standards expected by those who receive and/or review it. The third criterion considers whether, on balance, the group experience satisfies, rather than frustrates, the personal needs of individual members. Building on this framework and considering the multilayered nature of scientific ecosystems, the following sections identify methods and measures for evaluating: (a) team dynamics (e.g., team composition; teamwork processes; emergent states), (b) team performance outputs (e.g., intellectual merit, broader impact), and (c) the team's impact on individual members (e.g., career success, opportunities for learning and development).

From a national laboratory perspective, one notable gap is the lack of formal evaluation of team dynamics by laboratory leaders, which the committee views as a limitation. Traditionally, teams in national labs have been assessed based on project outcomes, not on the quality of their collaboration. Adopting a more rigorous approach to evaluating teamwork from a team science perspective would be valuable. An essential question to consider would be: How effectively did the team function?

Evaluating Science Team Dynamics

Some teams "burn themselves out" in the process of completing the team task, ultimately compromising their effectiveness. Other teams can sustain their performance, learn from one another, and improve over time. Likewise, team performance may be high, but members may be so dissatisfied with the team's dynamics that they do not want to continue working with the same members (this phenomenon is measured by what is known as team viability [Tekleab et al., 2009]).

The scientific literature on team functioning has identified attitudes, behaviors, and cognitive states (ABCs) that are "signatures" of highly effective teams (Salas et al., 2008).

Attitudes include psychological states such as *cohesion*, where members feel a strong bond and commitment to the team, and *trust*, which enables members to rely on one another; these attitudes play a pivotal role in sustaining high performance (Beal et al., 2003; De Jong et al., 2016). Additionally, *psychological safety*, an environment where team members feel safe to speak up, ask questions, and challenge ideas without fear of negative consequences, also enhances team performance (see also Chapter 4; Frazier et al., 2017).

Behaviors include core team processes that highlight interaction among members (Marks et al., 2001). For example, effective communication can ensure that information flows freely—reducing misunderstandings, aligning efforts, and improving performance (Marlow et al., 2018).

Coordination enables members to align their actions so that tasks are integrated seamlessly (Rico et al., 2008). Dysfunctional types of conflict, such as relational conflict (tension between team members) and process-related conflict (disagreements about logistics) reduce productivity, whereas task conflict (disagreements about the content of work) may increase performance under certain circumstances (de Wit et al., 2012).

Emergent *cognitive states*, such as shared mental models and transactive memory systems, allow teams to operate smoothly and efficiently by creating a common understanding of tasks, roles, and distributed knowledge (Mohammed et al., 2021). Information-sharing allows teams to capitalize on each member's unique expertise, whereas team-learning enables members to collectively acquire and apply knowledge to achieve common goals, both of which enhance team performance (Mesmer-Magnus & DeChurch, 2009; Wiese et al., 2021).

The broader team literature demonstrates that teams that develop and nurture the ABCs of teamwork are well positioned to improve team well-being and performance. But research on teamwork specific to the science team context rarely assesses team emergent states and processes, focusing instead on performance outcomes captured via archival measures such as publications, patents, or grants. However, teams that excel do not focus on task completion alone—they also invest in sustaining these critical processes and psychological states over time (Salas et al., 2008).

Researchers can assess the quality of a team's ABCs by collecting self-reported data via surveys. Table D-1 in Appendix D provides a sampling of survey-based assessments used in the team literature, including a construct/scale description, measurement specifics (number of items, dimensions, rating scale), and references indicating scale development and validation evidence. Following the popular input-mediator-output-input team framework (Ilgen et al., 2005), scales in Table D-1 are divided into seven main categories:

1. compositional/individual difference surveys (e.g., team roles, collaboration readiness);
2. emergent states (affective states such as trust and cohesion, cognitive states such as team-learning and transactive memory systems, and behavioral states such as workload-sharing and task interdependence);
3. team behavioral processes (e.g., conflict, coordination);
4. team climate and context (e.g., work group inclusion, team perceived virtuality);
5. team leadership;
6. team outcomes (e.g., affective outcomes such as team viability and collaboration, productivity outcomes such as performance); and

7. composite team surveys, which measure a variety of dimensions, including team readiness, functioning, climate, and outcomes (e.g., TeamSTEPPS [Agency for Healthcare Research and Quality, n.d.]).

To facilitate an understanding of when these measures may be helpful, these categories are represented in the form of questions (e.g., Are team members positioned for effective teamwork? How happy are team members with how they worked together?).

Although most scales in Appendix D are self-reported, some are designed to be completed by peers (e.g., the comprehensive assessment of team member effectiveness by Ohland et al. [2012] for self- and peer evaluation). For some constructs—such as conflict (e.g., Jehn & Mannix, 2001), transactive memory systems (e.g., Lewis, 2003), and psychological safety (e.g., Edmondson, 1999)—there is consensus on measurement, with most research utilizing the most popular scale. In contrast, constructs such as cohesion, team climate, team viability, and team performance currently have no agreed-upon measure in the team literature (see Appendix D).

Considerable variability exists for these measures regarding validation evidence, with more robust methods showing consistent factor structures over multiple samples and demonstrating favorable psychometric properties and multiple forms of validity (e.g., content, discriminant, convergent, predictive). For example, seeking to validate 50-, 30-, and 10-item versions of their team process scale, Mathieu et al. (2020) utilized data from 700 teams across laboratory and field contexts to demonstrate a consistent confirmatory factor structure over 10 samples, along with high content and discriminant validity.

Context (e.g., level of virtuality, nature and difficulty of team tasks, resources and support, team culture) needs to be considered carefully when determining what scales to adopt. Because most of the scales in Appendix D were developed in the broader team literature, adaptations in wording may be needed to fit science teams.[1] Although scale adaptations (e.g., changing the item context or referent, shortening scales, adding new items) are widespread in the team literature because of varying types of teams and tasks, adaptations may introduce threats to validity and psychometric properties (e.g., Heggestad et al., 2019). Justifying scale adaptations and providing evidence to support the validity of scales altered to fit a science team context would be possible but would require funding.

[1] The items for many of the scales provided in Appendix D are freely available at https://ctsi.psu.edu/research-support/team-science-toolbox/assessment/

Evaluating Science Team Performance Outputs

The outputs that science teams and multiteam systems produce—such as publications, invention reports, patents, funding, and developmental opportunities for junior scholars—can be valuable indicators of their effectiveness. These metrics can reflect a team's ability to generate novel ideas and solutions and advance scientific knowledge. A consistent flow of quality scientific output suggests that the team is actively engaged in research with practical applications (Hall et al., 2018; Trochim et al., 2008) and may indicate that the team is successfully integrating different expertise and perspectives and has strong collaboration and synergy. Thus, performance outputs can serve as key measures of team productivity and the tangible impact of research efforts (Xu et al., 2022; Yang et al., 2022).

Publications

Publishing scientific articles is a fundamental outcome of science teamwork, as publications can disseminate research findings to the broader community, contribute to the body of knowledge, and establish the credibility of the team's work. The collaborative process of writing and submitting manuscripts involves synthesizing different perspectives, adhering to rigorous methodologies, and presenting coherent and impactful narratives. The quality and quantity of publications can be evaluated by examining a variety of metrics such as the number of articles published, the impact factors of the journals in which they appear, and the citation rates they receive. Furthermore, evaluating the collaborative process leading to publication—such as the division of labor, the integration of different disciplinary insights, and the ability to meet deadlines—provides valuable information on the team's operational efficiency and cohesion (Hall et al., 2018; Nancarrow et al., 2013; Shuffler & Carter, 2018). *Bibliometric analysis* is a research evaluation methodology rooted in information science (Lyu et al., 2023). It uses statistical methods to analyze patterns in publications and citations, and it is rooted in the principle that the impact and influence of research can be quantified by examining how it is cited and used by other researchers.

There are different approaches to using publication output as a performance metric for science teams. Beyond simply counting the number of publications produced by a science team, researchers studying scientific collaboration have also assessed the quality of publications by considering their citation counts (Uzzi et al., 2013). Some scholars have used impact factors of the journals in which the publications appear (Llewellyn et al., 2020, 2024). Using impact factors and/or citation counts to evaluate science team performance has both advantages and disadvantages. On the positive side, these metrics can provide quantifiable measures of the potential influence and reach of a team's research. High citation counts suggest that the team's work is being recognized and used by other researchers, indicating its relevance and impact within the scientific community. Similarly, publishing in high-impact journals can signal that the team's research meets high standards of quality and significance, as these journals often have rigorous peer-review processes and are widely read. Demonstrating team performance through these metrics may be beneficial for securing funding, establishing collaborations, and enhancing the reputation of both the team and their embedding institution(s) (Carpenter et al., 2014). However, there are also multiple drawbacks to relying solely on citation counts and impact factors to evaluate science team performance. These metrics can be misleading, as they do not necessarily reflect the quality or innovation of the research (Donaldson & Cooke, 2014; Michalska-Smith & Allesina, 2017). For instance, citation counts for a team could be inflated by a few highly cited papers, which may not represent the overall contribution of the team. Additionally, a journal's impact factor reflects the average citation rate of all articles within that journal, not the specific impact of any single article, which can make it a poor indicator of individual team performance in many cases (Waltman & Traag, 2021).

For teams with interdisciplinary and/or transdisciplinary research goals, evaluating the degree to which publications integrate knowledge, methods, and perspectives from multiple disciplines to address complex research questions can be relevant (Laursen et al., 2022; Tremblay et al., 2011). Evaluation of interdisciplinarity can be approached through several key indicators and methods. For example, a qualitative evaluation of interdisciplinarity could involve peer review and expert evaluation, where feedback is solicited from experts in different disciplines to assess the perceived interdisciplinarity of the team's work (Mansilla, 2006). These peer reviews and expert panels can provide valuable qualitative insights into how effectively the research integrates and advances knowledge across multiple fields. Additionally, self-reported interdisciplinarity can be included, where the research team conducts a self-assessment, reflecting on their interdisciplinary practices, the integration of knowledge from various disciplines, and the challenges and benefits they encountered while working across these different fields (e.g., Palmer et al., 2016).

Quantitative analysis of disciplinary differences can involve examining the disciplinary backgrounds of team members listed as authors on scientific publications, categorized by their departmental or institutional affiliations and areas of expertise. Additionally, analyzing the variety of citations and references in the team's publications can reveal the extent to which the team draws on and contributes to multiple disciplines. Assessing the variety of publication venues, particularly the range of journals in which the team's work is published, also provides insight into the research's relevance across different academic fields (Carr et al., 2018). This can be measured by categorizing journals by disciplinary focus and calculating the proportion of publications in each category. Considering impact factors and target audiences of journals, as well as citation counts, is important in this context, as inclusion in high-impact, interdisciplinary journals indicates that the research is accessible and valuable to a broad academic audience beyond a single discipline (e.g., Carr et al., 2017; Leahey et al., 2017; Okamura, 2019).

Invention Reports and Patents

Invention reports and patents can be valuable metrics for evaluating the success and impact of team science, particularly in fields where research has the potential to lead to practical applications and technological innovations. These indicators generally offer tangible evidence of a team's ability to translate scientific discoveries into real-world solutions, reflecting the practical significance and economic value of their research (Fortunato et al., 2018; Tigges et al., 2019; Wuchty et al., 2007).

Invention reports serve as preliminary documentation of novel ideas or technologies developed by a team, and they provide a gate check before applying for a patent (e.g., Harvard University, n.d.; National Institute of Health SEED, n.d.). These reports may be useful for evaluating the creativity and innovative capacity of a science team, as they capture the early stages of ideation and problem-solving. The number and quality of invention reports may indicate a team's effectiveness in generating new ideas and their potential for future technological breakthroughs (University of Michigan Innovation Partnerships, 2024; Tigges et al., 2019).

Patents, on the other hand, represent a more advanced stage of innovation, providing legal protection for inventions and enabling commercialization. The number of patents filed and granted may serve as a key indicator of a team's success, not only in developing novel technologies but also in advancing these ideas to a stage where they have clear utility and market potential (Allen et al., 2016; Vestal & Mesmer-Magnus, 2020). Patents also contribute to the broader impact of team science by facilitating the transfer of knowledge and technology from academic settings to industry and society, potentially leading to new products, processes, and services that address societal needs (National Center for Science and Engineering Statistics, 2024).

However, although invention reports and patents are important indicators of innovation, they have potential limitations in terms of evaluating team science across all fields. For example, newer fields of research may have higher invention potential compared with more established fields, by virtue of how much "blank space" exists. As a result, the number of invention reports and patents could potentially be skewed by the type of scientific research being conducted, irrespective of a science team's quality. Therefore, although publications, invention reports, and patents can be useful for assessing certain aspects of team science performance, these approaches can be complemented by broader evaluative approaches that include narrative accounts of success. A holistic perspective to team science evaluation can enable a more comprehensive evaluation of team contributions, acknowledging the diverse forms of impact that team science can achieve across different disciplines (e.g., Wooten et al., 2014).

Invention reports and patents are also used as key output metrics in industry to help appraise, as part of a broader evaluation matrix, the return on investment at the project, department, and organizational levels. Also trackable are the conversion of patented and unpatented technologies into new commercial products (Nerkar & Shane, 2007) that yield monetary gains and the percentage of sales that come from newly innovated products. However, these output metrics need to be put into context with the macroeconomic environment, as changes in the economy will likely result in changes to inputs such as funding for research and development and outputs such as revenue (Mezzanotti & Simcoe, 2023). In addition, the quality of innovation management systems between and within companies and industries can vary widely, which can strongly influence output metrics and be disconnected from the quality of team science taking place on a particular project. The quality of innovation management systems is important enough that the International Organization for Standardization (2019) has issued a comprehensive set of guidelines: *Innovation management—Innovation management system*. As a result, from a team science perspective, control variables can be confounded by external and internal factors that hinder the ability to adequately isolate how an organization's structural changes directly impact the quality of team science and associated outcomes (Memon et al., 2024). Temporal impacts also need to be considered, as any change that is made to a procedure or process will usually take months or years to impact scientific and/or innovation output metrics (Miller et al., 2021). As a result, it can be difficult to parse the correlational and causational factors when using invention reports, patents, and other innovation metrics as a proxy for the effectiveness of team science.

Research Awards

Securing research funding is sometimes used as an output metric to evaluate a science team's success. Effective team science can lead to the development of new fields or lines of research that attract funding and inspire new sponsored programs or institutional strategic initiatives. This influx of resources enables teams to explore innovative ideas, support interdisciplinary collaborations, and build research capacity that would otherwise be unattainable. For example, the National Academies Keck Futures Initiative (NAKFI) was a 15-year program supported by a $40 million grant from the W. M. Keck Foundation. Its goal was to advance the future of science by supporting innovative interdisciplinary research ideas generated during think tank–style conferences. Each of these conferences focused on different real-world challenges. Attendees were able to compete for seed fund grants, allowing them to pursue what the NAKFI program viewed as bold and new research ideas (for more information, see National Research Council, 2018).

Funding serves as a catalyst for scholarly growth, providing the necessary support for conducting high-impact research, building infrastructure, and training the next generation of scientists. However, the true measure of success can lie in how well these financial resources are leveraged to generate meaningful scientific contributions, address complex societal challenges, and foster sustained academic and community engagement (Shrivastava et al., 2020; Tebes & Thai, 2018). Therefore, although the ability to secure research dollars is a critical component of evaluating team science, it needs to be considered in the context of how these resources are used to achieve broader intellectual and societal impacts.

Other Performance Output Considerations

As mentioned throughout this discussion, those researching and evaluating science teams ought to take a broad perspective when considering scientific outputs. This can include intellectual output beyond publications and patents. For example, science teams can sometimes produce spin-off projects based on new ideas generated, which sometimes lead to new grants. They might create new methodologies from combining approaches developed in separate fields or from addressing a need in their innovation process. Science teams can also be evaluated on outcomes such as development of new scientific software or unique datasets that came out of their project, either out of need or from discovery; datasets are particularly important given that they require intensive interdisciplinary collaboration.

A related form of evaluation pertains to how the team members are changing. Science teams can create an informal learning culture where knowledge and skills are transferred as the research progresses. This could include learning new methods for research or creating a shared vocabulary that transcends disciplinary language barriers (Dietl et al., 2023; Tannenbaum et al., 2009). In this process, science team members are developing collaboration competencies. While these competencies are important, they might not always be tracked consistently (Strimel et al., 2014). This informal learning, however, is crucial to the scientific ecosystem, as it is the main way new knowledge is acquired after graduate school.

Although some funders already account for educational outcomes (e.g., students graduated, theses supported), evaluation of team science needs to also consider interdisciplinary integration in student research (e.g., Laursen et al., 2023). Team science projects commonly lead to the development of new courses and even new degree programs based upon the need for interdisciplinary graduate training. What is more, the enhanced professional networks developed through collaboration cannot be captured via coauthor networks. These social–professional ties are important to track because they can lead to collaborations that are not normally traced with traditional methods.

New subgroups in professional societies can be produced when a research topic has broader implications and may lead to new interdisciplinary societies (e.g., funding for smart cities research led to the development of technical groups and dedicated meetings in computer science societies). In this vein, researcher output can also lead to articles reflecting on the implication of findings for science policy and to informal science articles, such as online magazines or blogs, or popular press articles in science magazines. These kinds of outreach activities become increasingly important to demonstrate the broader impact science teams can have on the community at large and to educate the public about new discoveries.

Impact on Financial and Human Resources for Communities and Institutions

When evaluating team science output, it is also crucial to measure and document the impact these efforts have on the institutions and communities in which the science teams operate. For example, science team output may directly impact training and development opportunities for junior scholars. Indicators such as the creation of new academic programs and classes at universities, the integration of cutting-edge research findings into curricula, and the inclusion of team science outcomes in textbooks and other education resources are key metrics to consider (Steer et al., 2017; Wallen et al., 2019). These indicators could help assess whether the team is producing new knowledge that is being disseminated to relevant communities and whether the next generation of scientists is gaining a comprehensive understanding of interdisciplinary approaches and collaborative research methods.

Furthermore, it is important to track and document the competitive advantages that team science can provide for institutions, particularly in terms of financial profitability and resource acquisition. Many of the metrics typically used to assess the performance of science teams, such as publications, patents, and grant funding (noted previously), can also be applied at the center, institution, or community levels. For example, metrics such as increased grant funding, which is often a result of successful interdisciplinary collaborations, can serve as valuable indicators of the initiative's financial impact. This approach provides valuable insights into whether science teams are achieving their desired outcomes and whether institutional-level interventions are effectively driving these results.

Additionally, documenting the recruitment and retention of talented personnel highlights the role of team science in making institutions more attractive to scholars and professionals. These factors are crucial for understanding how well the institution is leveraging its commitment to innovative, collaborative research to enhance its overall standing and resource base, as well as its ability to positively impact local and global communities for the benefit of their workforce and for scientific reach (e.g., Parilla & Haskins, 2023; Valero & Van Reenen, 2019).

At the macro level, the impact of team science on connections among groups and disciplines could be measured and documented to evaluate whether large-scale initiatives are having the desired impact on the communities that have invested in them and on the communities where these initiatives are invested. Metrics such as the development of more interconnected publication networks of scientists from different disciplines, the strengthening of bonds within and across research groups, and the establishment of connections with relevant agencies and other invested groups are all potential indicators of team science success. As an example, the National Science Foundation (NSF) had funded the Research Coordination Networks program to advance a field or create new directions in research by supporting investigators across international, geographic, and organizational boundaries (National Science Foundation, n.d.). Metrics that assess these connections might provide insight into how effectively team science initiatives are breaking down silos, facilitating knowledge, promoting the translation of scientific findings into practical applications, and improving the communities that they draw from and are embedded in. Therefore, by systematically tracking the development and evolution of connectivity among relevant parties, and their impact on science and on various communities, evaluators can better understand the role of team science in advancing scientific progress.

Evaluating Broader Impacts

Defining societal impact in research and academia goes beyond the traditional metrics of success, such as impact factor, publication counts, invited talks, and patents. *Societal impact* is the tangible influence that research has on society, encompassing the ways in which knowledge creation improves public well-being, shapes policies, and drives societal advancements. In 2020, the United Nations (UN) published the report *Shaping the Trends of Our Time*, which lists five interconnected megatrends—the greatest challenges facing humanity—as (a) climate change and environmental degradation, (b) demographic trends and population aging, (c) sustainable urbanization, (d) digital technologies, and (e) inequalities. The UN prioritized these megatrends, which will shape the world for the next several decades, because they are human challenges that can be modified by human choices (United Nations, 2020). Effective team science can help address each of these societal challenges by accelerating advances in science and technology and developing practical and scalable solutions. While traditional metrics highlight the academic reach of research, they often fail to capture how that research contributes to solving real-world problems such as those identified by the UN. To comprehensively assess societal impact, one must consider alternative measures, such as community engagement, public policy influence, and the practical application of research findings in nonacademic sectors (D'Este & Robinson-García, 2023).

One of the key challenges in measuring societal impact is the significant time lag between when research is conducted and when its broader societal effects become evident (Siar, 2023). For instance, a study on public health might not show its true societal benefits until years after the findings have been applied in policy reforms or health care interventions. Similarly, environmental research could take decades before its recommendations lead to significant ecological or regulatory changes. As a result, tracking societal impact requires a long-term view and an understanding that traditional, short-term metrics may not capture the full scope of influence.

Another difficulty lies in determining who is responsible for tracking societal impact. Unlike academic citations, which are relatively easy to quantify through established databases, societal impact is diffuse, involving multiple entities such as government agencies, nonprofits, industry partners, and community organizations. Researchers may lack the resources or time to systematically track how their work is being utilized outside academia (e.g., Oliver et al., 2014). As such, institutions may need to play a larger role in this effort, possibly through dedicated offices or staff that monitor the application of research in broader societal contexts. Collaboration with external partners who are involved in the implementation of research could also provide valuable insights.

Supporting such tracking efforts is another significant hurdle, as these efforts require a focused effort (Celeste et al., 2014), particularly to go beyond anecdotal evidence and develop robust methods for documenting influence. Universities and research institutions need to allocate resources to track the diffusion and implementation of research across various societal domains. This could involve establishing partnerships with policymakers, industries, or public organizations that can monitor and report on the outcomes of research projects. Furthermore, platforms where researchers can share the broader impacts of their work, such as policy briefs or community impact reports, could help document societal contributions more systematically.

Ultimately, the challenge of defining and tracking societal impact invites a broader conversation about what one values in research. Expanding the understanding of impact to include societal contributions requires a shift in both institutional priorities and reward systems. Instead of focusing solely on traditional academic outputs, institutions can recognize and incentivize efforts that engage with communities, influence public policy, and address pressing societal challenges (Ozer et al., 2023). Broadening the criteria for success fosters a research ecosystem that not only advances knowledge but also drives meaningful change in the world.

The Translational Science Benefits Model[2] is a framework that helps determine the range of societal impacts research can have on society. The model takes into consideration a number of potential domains that can be influenced, such as policy, economic, health or clinical, as well as the community. One valuable aspect of this model is its ability to help researchers think in the planning phase about how their research will have impact and how they will measure the benefits of its impact. For example, in health care, researchers can examine whether scientific papers are referenced in policy documents and whether these policies lead to improved health care or societal outcomes.

Societal trust in science is another critical component of understanding science's broader impact. If people in society have a high degree of trust in scientific findings, research-backed policies and clinical practices may be more likely to be accepted and implemented effectively. Conversely, if public trust in science is low, even the most robust policies and practices may struggle to gain traction (Anderson et al., 2024; Goldenberg, 2023).

Evaluating a Science Team's Impact on Individual Members

Psychological Impact

Evaluating the impact of being part of a science team on an individual team member can involve several important dimensions (Tay et al., 2023). One key aspect is individual well-being, which encompasses job satisfaction, engagement, and a sense of meaning and professional identity (Gibson et al., 2023). Being part of a collaborative team can enhance these elements by providing a supportive environment where scientists feel valued and

[2] More information about the Translational Science Benefits Model is available at https://translationalsciencebenefits.wustl.edu/

connected to a larger purpose. When team members experience high levels of well-being, they are more likely to be motivated, productive, and committed to their work (Gibson et al., 2023). Another important factor is the individual's experience of inclusion, or even fusion within the team (Swann et al., 2009). When scientists perceive a fair and inclusive environment, they are more likely to contribute effectively and feel a sense of belonging, which is crucial for maintaining a healthy and positive team dynamic (Gibson et al., 2023; Salas et al., 2015).

Learning and development are also critical outcomes of team participation. Scientists not only advance their own skills and knowledge through collaboration but also contribute to the development of those around them (Bennett & Gladlin, 2012). This reciprocal process of learning fosters a team culture of continuous improvement and innovation, which can have long-lasting benefits for both the individual and the group (Thayer et al., 2018).

Professional Networks

Being part of a science team could significantly impact an individual scientist by broadening and diversifying their network of collaborators. This expanded network can be tracked over time, providing insights into the development of the scientist's professional relationships (Fortunato et al., 2018; Okamoto & Centers for Population Health and Health Disparities Evaluation Working Group, 2015). As a scientist works with new colleagues across different disciplines, their network might grow not only in size, but also in perspective diversity, which can lead to richer, more innovative collaborations (van Knippenberg et al., 2020). This diversification of connections may enhance the scientist's ability to tackle complex research problems by bringing in fresh perspectives and expertise from a wide array of fields.

Furthermore, the social capital gained from being part of a diverse science team or group may facilitate the recruitment and retention of even more diverse team members over time (e.g., Harris et al., 2025). As scientists work together with new colleagues from different networks, they not only produce collaborative outputs such as publications, but also can establish lasting professional relationships. This is particularly evident in academia, where the freedom to pursue various research topics and the support provided by universities or agencies—such as through multidisciplinary workshops and collaborative programs—make it easier to connect with new people (Ertas et al., 2003; Hannon et al., 2018). Additionally, the transient nature of student populations in academic settings provides a continuous influx of new talent, further enriching the team's diversity and collaborative potential.

Career Success

Strengthening a network of collaborators, including participating in team science, can also have meaningful outcomes for a scientist's career. As collaborative relationships depend and become more productive, they can lead to more significant achievements, such as coauthored publications, joint grant applications, and shared researched projects, that are reflected on the scientist's curriculum vitae. The value of these connections is often seen in the sustained collaborations that result in regular outputs over many years, which can be particularly beneficial in an academic setting, where long-term partnerships may be more feasible (Bu et al., 2018). For example, it is generally a baseline requirement in industry that employees will develop a proven track record of being able to collaborate effectively; this ability can be considered in the recruitment and promotion processes (Klein & Falk-Krzesinski, 2017). A key differentiator in hiring can be an individual's experience with complex collaborations in team science, such as inter- or transdisciplinary work, especially with teams that are geographically dispersed. This may be true for global industrial firms, where team science can stretch across disciplines and geographies (Hung et al., 2021; Jones et al., 2008; Mazzucchelli et al., 2021).

Potential Limitations

It is important to recognize certain limitations when evaluating the impact of team science at the individual level. While many aspects discussed are inherently positive, such as the expansion of professional networks and the promotion of learning and development outcomes, some scholars have highlighted significant trade-offs and potential negative consequences associated with team participation (Benson et al., 2016; Conn et al., 2019). For instance, Forscher et al. (2023) underscored the risk of unaccountable leadership within large-scale team science initiatives, and Mäkinen et al. (2025) identified challenges faced by untenured faculty in gaining recognition for their contributions to interdisciplinary research. Additionally, research has shown that for junior employees, membership in multiple teams is associated with greater role ambiguity, lower job performance, and higher absenteeism (van de Brake et al., 2020). Berkes et al. (2024) demonstrated that researchers who engage in interdisciplinary work early in their careers tend to have less career success and stop publishing sooner than those who initially stay within their discipline. Ensuring that early career researchers receive guidance, recognition, and resources can help mitigate these risks and promote more sustainable career paths in interdisciplinary research. Taken together, these findings suggest the potential trade-offs inherent in team science participation warrant consideration.

CONCLUSION AND RECOMMENDATION

Conclusion 5-1: Data collection and evaluation, supported by both institutions and science team leaders, are critical for answering questions about key features of science teams:

- *How social processes on the team are unfolding (e.g., team members' perception of experiences of participation on the team, team member satisfaction, psychological safety, trust).*
- *What the team is producing (e.g., successfully completed team objectives, publications, patents and invention reports, research grant applications and awards, educational outcomes).*
- *What impact the team is having on individual members (e.g., well-being, skill and knowledge advancement, growth of professional networks, career success).*

Recommendation 5-1: Funding agencies, including the National Science Foundation, the National Institutes of Health, and the many other agencies and foundations that support research, should require that the science teams they support develop an evaluation plan to assess their effectiveness and impact. The plans should incorporate team dynamics (e.g., social processes), team performance (e.g., bibliometric metrics), and impact on members (e.g., learning and development outcomes). Regular review periods should be established with the team to monitor and track progress and team effectiveness.

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6

Forward-Looking Research Recommendations and Infrastructure Needs

This report has discussed the existing research on science teams, as well as research on teams more generally, with particular attention to best practices, external support, and evaluation. Team science has already demonstrated benefits in innovation and problem-solving, and there is reason to believe that strengthening both the way team science is performed and the way it is researched and supported would strengthen these benefits and lead to more effective teams. This final chapter reviews the subjects discussed in the previous chapters and assesses needs for additional research specific to the science of team science.

BEST PRACTICES

The current literature on science teams indicates a pressing need for systematic empirical research to evaluate interventions in real-world team settings. While numerous best practices and interventions have been identified, much of the supporting evidence remains anecdotal or correlational. Chapter 3 highlights how most studies are primarily case based or correlation driven, leaving a gap in experimentally validated best practices that can be applied widely across various team science contexts. By funding real-time studies, research sponsors can facilitate rigorous experimental research that could lead to more generalizable and reliable data, fostering the development of evidence-based guidelines that directly improve team science processes and outcomes. Table 3-1 in Chapter 3 details possible future research questions to address that would strengthen the evidence for best practices.

Science teams often encounter a variety of challenges, ranging from interdisciplinary differences to unique project requirements and team compositions. Thus, interventions need to be tailored to each team's specific circumstances to enhance effectiveness. Chapter 3 notes the diversity of team needs and configurations, which affect the efficacy of interventions labeled as "best practices." For example, research shows that establishing norms around tool use needs to account for individual team characteristics, such as team composition and the cultural or linguistic backgrounds of team members, to promote efficient collaboration. Consequently, a reflexive approach that adapts practices based on each team's requirements and experiences can lead to more effective team functioning. This tailored approach not only respects the unique nature of each science team but also encourages team members to critically evaluate and refine their workflows, fostering adaptability and resilience.

Virtual collaboration tools, if thoughtfully selected and integrated, can address geographic and temporal challenges that often arise in hybrid or distributed teams. Chapter 3 emphasizes that these tools need to be evaluated based on their alignment with team configuration, accessibility needs, and the skills of team members. For example, ensuring that tools include features such as screen sharing, closed captioning, and language translation can help accommodate team needs, increasing participation and improving communication. However, improper or inconsistent use of these tools can hinder trust and create conflict, particularly if team members feel that tools lack transparency or do not provide a secure environment for open communication.

Moreover, periodic reassessment of tool efficacy is recommended as team compositions and technological options evolve. Regularly revisiting tool usage norms can help avoid potential misalignments between team needs and available functionalities, ensuring that the technology remains a facilitator rather than a barrier to effective collaboration. The evolving nature of team science necessitates a flexible approach to tool integration, underscoring the importance of establishing clear norms and ensuring that all members are adequately trained to use these tools effectively.

In summary, supporting science teams through tailored approaches, well-integrated virtual tools, and robust research funding are essential for enabling effective and adaptable team science practices. These recommendations reflect the heterogenous configurations and complex dynamics of science teams, underscoring the importance of real-time research, a flexible methodology, and carefully chosen virtual collaboration tools to foster productive and resilient scientific collaboration.

INSTITUTIONAL AND EXTERNAL SUPPORT

As discussed in Chapter 4, a comprehensive institutional approach is critical to support successful team science outcomes. This includes considering team science in decisions regarding personnel, funding, incentives, technology, and policy. However, many institutions lack clear practices or infrastructure for facilitating such a holistic approach, and limited research exists to identify which specific supports are most effective in fostering successful team science environments. Institutional challenges, such as inadequate incentives for teamwork in promotion and tenure criteria, limited access to collaborative technologies, and lack of administrative support, can all hinder team performance. To optimize team science, more research is needed to understand how institutional practices influence collaboration outcomes, allowing for the development of informed strategies for supporting effective teamwork.

To advance team science, funders and institutions need to encourage best practices by recognizing team science contributions in hiring, tenure, promotion, and awards. Traditional evaluation methods, such as publication count and grant funding, often overlook collaborative efforts and are disadvantageous to scientists involved in cross-disciplinary projects. Revising these criteria to value team science roles—such as leadership in large projects and contributions to shared research outcomes, as well as additional contributions that may include mentoring, community-based research, and other work—would incentivize engagement and address current disincentives. Additionally, simplifying data sharing, open-science practices, and ethical review processes can alleviate administrative burdens on science teams, thereby enhancing collaboration. For instance, open-science frameworks that support sharing data and research products streamline workflows and promote transparency, benefiting both individual scientists and their teams.

Active support from funders for research on team science effectiveness is also crucial. Investing in studies on team science competencies, the impact of professional development (e.g., workshops, courses), and metrics to evaluate development of these competencies will provide insights into optimizing team dynamics. This includes research on how incentives affect team science prevalence and success across institutions, helping funders understand and refine policies that foster collaboration. Furthermore, studies examining institutional support structures—like research development professionals and team facilitators—can reveal their contributions to project efficiency and success. For a sustained impact, funders and institutions need to ensure accountability in adapting policies to support team-based science effectively. Addressing these areas comprehensively will not only support team science but also contribute to high-quality, impactful scientific outcomes across disciplines.

EVALUATION

To effectively evaluate science team outcomes, funders, institutions, and researchers need to prioritize three core questions that capture the essential aspects of team effectiveness: the social processes within the team, the tangible outputs produced, and the positive impact on individual members. Evaluating team dynamics, including social processes such as communication, cohesion, and psychological safety, is fundamental, as these factors directly influence a team's ability to collaborate and achieve high performance. Research suggests that well-functioning social processes foster trust, reduce conflict, and enable teams to address complex tasks more efficiently.

Evaluating outputs—such as publications, patents, and other research deliverables—enables a direct assessment of the team's productivity and contributions to scientific knowledge. By measuring both quantity and quality of these outputs, evaluators can gain insights into the team's innovative capacity and impact within the broader scientific community. That said, evaluation needs to move beyond that which is easily counted. This can include the study of how scientific collaborations adapt scientific concepts, how they change professional networks and societies, as well as the nature and form of material artifacts produced. Additionally, understanding the broader impact of these outputs, including societal or policy contributions, provides a comprehensive view of the team's success.

Finally, assessing the team's impact on individual members is crucial, as participation in team science can significantly affect career development, professional satisfaction, and future collaborative opportunities. Positive experiences within science teams can lead to personal growth, expanded professional networks, and improved career trajectories. Emphasizing individual well-being and professional development aligns with the evolving goals of modern scientific research, which increasingly prioritizes inclusivity and career sustainability for team members. For a comprehensive evaluation, funding agencies and institutions can consider multiple evaluation criteria tailored to specific team goals, resources, and evaluation purposes. A multidimensional evaluation approach that captures short- and long-term outcomes enables a nuanced understanding of team performance, guiding future investments and fostering a supportive environment for team science initiatives to thrive.

IDENTIFICATION OF RESEARCH GAPS

While there has been substantial application of team science principles derived from the social and organizational sciences (e.g., social and organizational psychology, organizational behavior, cognitive science), the empirical basis for applying these insights to science teams is still limited. This gap is crucial to address, as science teams are distinct from the types of teams typically studied outside of science, raising concerns about the generalizability of these findings. The committee suggests that a better understanding of these distinctions requires context-specific research focused on the unique structures and dynamics of science teams.

Funders need to provide more funding mechanisms for the scientific study of science teams. Indeed, major funding bodies such as the National Science Foundation and National Institutes of Health emphasize the critical importance of team science in solving complex global problems, but the support needed to fund the study of science teams is lacking. This disparity is problematic given the complexity of studying science teams, which requires both significant financial resources and specialized methodological approaches tailored to scientific collaboration contexts.

CONCLUSION AND RECOMMENDATION

Conclusion 6-1: The research translating findings on the functioning of teams general to the functioning of science teams is incomplete for reasons that include insufficient funding and a lack of professional recognition and reward for the study of science teams. Specifically needed are:

- *Studies focused on the science team context that explore the application of existing theories to the unique processes and dynamics that distinguish science teams from traditional organizational teams.*
- *Studies of team science competencies and interventions that allow for robust statistical analyses or pre- and post-testing to build the empirical evidence base for team science learning, training, and professional development in real time.*
- *Data-driven research, including longitudinal studies, to better understand team science outcomes.*
- *Research to identify and investigate institutional policies and practices that reinforce or serve as barriers to team science, such as the support structures universities can provide (e.g., research development professionals, team facilitators), how these affect team science processes and outcomes, and other incentives that influence the conduct of team science.*
- *Research into the effectiveness of virtual collaboration tools and how these relate to the specific configuration of hybrid and virtual teams, including factors such as geographic distribution, temporal dynamics, and communication needs.*

Recommendation 6-1: Funders interested in supporting the conduct of science should prioritize research on, and provide sufficient funding for, the application of findings from the broader study of teams to the science context. Areas of prioritization may include but are not limited to studies that incorporate both qualitative and quantitative data to build empirical evidence about the science context and research evaluating institutional policies and supports for science teams.

Appendix A

Committee Biosketches

DIANA L. BURLEY (*Co-chair*) is a global cybersecurity expert with more than 30 years of experience driving digital transformation, implementing cybersecurity workforce initiatives, and promoting an equitable global technology community. She is currently vice provost for research and innovation at American University where she also leads the Khan Cyber & Economic Security Institute and serves as a member of the faculty. As both the university's chief research officer and chief innovation officer, Burley oversees the university-wide research and development portfolio, research partnerships, and strategic initiatives to catalyze discovery. She also directs the university's Translating Research into Action Center (TRAC), a $6 million National Science Foundation–funded initiative launched to strengthen the university's capacity to advance positive societal impact through evidence-driven policy and practice. Burley regularly advises government officials and offers thought leadership at executive forums. Her board service includes the Cyber Future Foundation and the Global Cyber Security Advisory Group, and she has been honored by the Executive Women's Forum, *SC Magazine*, Association for Computing Machinery, and others for her leadership in building the global cybersecurity workforce. Burley earned her PhD from Carnegie Mellon University.

MO WANG (*Co-chair*) is the University Distinguished Professor, Lanzillotti-McKethan Eminent Scholar Chair and the associate dean for research and strategic initiatives at the Warrington College of Business at the University of Florida. He is also the chair of the Management Department and the director of the Human Resource Research

Center at the University of Florida. Wang specializes in research areas of organizational behavior and human resource management, especially on team science. He received numerous research awards for his research in these areas, including the Academy of Management (AOM) HR Division Scholarly Achievement Award; Careers Division Best Paper Award; European Union's Erasmus Mundus Scholarship Award for Work, Organizational, and Personnel Psychology; Emerald Group's Outstanding Author Contribution Awards; Society for Industrial-Organizational Psychology's (SIOP) William A. Owens Scholarly Achievement Award; and the *Journal of Management* Scholarly Impact Award. Wang also received a number of early/mid-career contribution awards from AOM, the American Psychological Association (APA), the Society for Industrial and Organizational Psychology (SIOP), and the Society for Occupational Health Psychology (SOHP). He is an elected Foreign Member of Academia Europaea and a fellow of AOM, APA, the Association for Psychological Science, and SIOP. Previously, Wang was the president of SOHP and SIOP. He received his PhD from Bowling Green State University.

DOROTHY CARTER is an associate professor of management in the Eli Broad College of Business at Michigan State University. Her research focuses on how leaders, teams, and larger multiteam systems can collaborate effectively to achieve shared goals in a variety of contexts including the military, space exploration, and team science. Carter's research on leadership and teamwork has appeared in numerous top journals within the organizational sciences, as well as in interdisciplinary outlets. She has received several research awards including the Rising Star in Leadership Research Award from the Academy of Management's Network of Leadership Scholars, the Charles B. Knapp Early Career Scholar in the Social Sciences Award from the University of Georgia, and the Early Career Award from the Interdisciplinary Network for Groups Research. Carter's research program has been supported by funding from the National Aeronautics and Space Administration, the National Science Foundation, the Army Research Institute, and the National Institutes of Health. She received her MS and PhD in industrial/organizational psychology from the Georgia Institute of Technology.

ERIN KAI-LING CHIOU is an associate professor of human systems engineering at The Polytechnic School, part of the Ira A. Fulton Schools of Engineering at Arizona State University. Her research focuses on human-automation interaction, job design with information and communication technologies, and trust in sociotechnical systems. Chiou's multidisciplinary and team-based research addresses complex work domains like education, health care, and defense. Recent research projects have been supported by the Department of Homeland Security, the National Science Foundation, the National Institutes of Health, and the Chief Digital and Artificial Intelligence Office. Chiou has served as a member of the Diversity and Inclusion Committee for the Human Factors and Ergonomics Society, including as chair for two years, and was a recipient of the society's inaugural Inclusion Award in 2024. She is a co-editor of *Advancing Diversity, Inclusion, and Social Justice Through Human Systems Engineering* (2020), a winner of the Outstanding Academic Title recognition by Choice for the 2020 Open and Affordable Textbook Award from Rutgers University Libraries. Chiou is also an associate editor for the *Journal of Cognitive Engineering and Decision-Making*. She received her MS and PhD in industrial and systems engineering (human factors and ergonomics) from the University of Wisconsin–Madison, where she was a National Science Foundation Graduate Research Fellow. Chiou has served as a reviewer and committee member for several National Academies of Sciences, Engineering, and Medicine efforts, including as a member for the consensus study on *Human-AI Teaming: State-of-the-Art and Research Needs*.

DEBORAH DIAZGRANADOS is an associate professor in the Department of Psychiatry at Virginia Commonwealth University's School of Medicine and the Director of Evaluation and Team Science for the Kenneth and Dianne Wright Center for Clinical and Translational Research. A leading expert in leadership and collaboration, her work emphasizes the dynamic interplay of context and individual connections in fostering effective teamwork. DiazGranados views collaboration as a dynamic process profoundly shaped by context and the strategic connections individuals make. Her research on shared leadership and collaboration has been particularly influential in demonstrating how to integrate knowledge across disciplines for innovation. DiazGrandos' contributions are evident in numerous publications within highly respected academic journals like the *Journal of Applied Psychology*, *Academic Medicine*, *Academy of Management Annals*, *American Psychologist*, and *Current Directions in Psychological Science*. Furthermore, the practical implications of her research extend beyond scholarly circles, with specific articles cited in key policy documents for governmental agencies and health care organizations, underscoring its tangible impact on practice and policy development. With a robust track record, DiazGranados has been a principal investigator (PI) or Co-PI on grants and contracts totaling over $10 million. She holds an MS and PhD in industrial-organizational psychology from the University of Central Florida.

STEPHEN M. FIORE is the director of the Cognitive Sciences Laboratory and Pegasus Professor with the University of Central Florida's (UCF's) Cognitive Sciences Program in the Department of Philosophy and the

Institute for Simulation & Training. He maintains a multidisciplinary research interest that incorporates aspects of the cognitive, social, organizational, and computational sciences in the investigation of learning and performance in individuals and teams. Fiore's primary area of research is the interdisciplinary study of complex collaborative cognition and the understanding of how humans interact socially and with technology. He is the past president of the International Network for the Science of Team Science and past president of the Interdisciplinary Network for Group Research. Fiore was a member of the expert panel for the Organisation for Economic Co-operation and Development's Programme for International Student Assessment, which focused on collaborative problem-solving skills. He was previously a member of the National Assessment of Educational Progress report *Collaborative Problem Solving*. Fiore was inducted into UCF's Scroll & Quill Society as recognition of his scholarship having an international impact. He also received UCF's Luminary Award as recognition for his work having a significant impact on the world, and UCF's Reach for the Stars Award, as recognition for bringing international prominence to the university. Fiore was given the title of Pegasus Professor, UCF's highest academic rank. He has a PhD in cognitive psychology from the University of Pittsburgh. Fiore has contributed to working groups for the National Academies of Sciences, Engineering, and Medicine in understanding and measuring 21st century skills and was a committee member of their *Science of Team Science* consensus study, which produced the 2015 report, *Team Science Effectiveness*.

MICHAEL C. FRANK is Benjamin Scott Crocker Professor of Human Biology in the Department of Psychology at Stanford University and director of the Symbolic Systems Program. He studies children's language learning and development, with a focus on the use of large-scale datasets to understand the variability and consistency of learning across cultures. Frank is a founder of the ManyBabies Consortium and has led open-data projects including Wordbank and the ongoing Learning Variability Network Exchange (LEVANTE) project. He served as president of the Cognitive Science Society, has edited for journals including *Cognition* and *Child Development*, and is the current co-editor in chief of the *Open Encyclopedia of Cognitive Science*. Frank has received awards including the Troland Award from the National Academy of Sciences and the FABBS Early Career Impact Award. He received his PhD in brain and cognitive sciences from the Massachusetts Institute of Technology

NICOLE B. MOTZER is the director of the Office of Research Development at Montana State University. She is actively engaged in the National Organization of Research Development Professionals and at the forefront of cutting-edge approaches to growing university research enterprises. Prior to that, she served as assistant director for interdisciplinary science for the National Socio-Environmental Synthesis Center. Motzer's expertise thus lies at the intersection of research development, interdisciplinarity, and team science. She has mentored hundreds of scholars and dozens of research teams through team science best practices, led several first-of-their-kind team science training and funding opportunities, and regularly coached research groups across the country and even the globe. In addition to a team science facilitator and trainer, Motzer is an interdisciplinary collaborator in topics ranging from interdisciplinary evaluation to marine spatial planning to grassland health. She is co-primary investigator (co-PI) on a National Aeronautics and Space Administration's Land Cover Land Use Change Award and on a National Science Foundation (NSF) GRANTED Award, and she served as PI of a global effort funded by the Gordon and Betty Moore Foundation. Motzer was named a visiting fellow for Michigan State University's Center for Interdisciplinarity for her practical contributions to interdisciplinary science as well as her work on interdisciplinary and research evaluation. She completed her PhD in geographical sciences at the University of Maryland, College Park as an NSF graduate research fellow. Motzer participated in and reviewed the proceedings for the National Academies of Sciences, Engineering, and Medicine's "Measuring Convergence in Science and Engineering" workshop.

MARK T. PETERS is the president and chief executive officer of MITRE, the global not-for-profit technology company that operates research and development centers worldwide. Previously, he was the executive vice president for National Laboratory Management and Operations at Battelle Memorial Institute with responsibilities for governance and oversight of the U.S. Department of Energy (DOE) and U.S. Department of Homeland Security national laboratories for which Battelle has a significant lab management role. Peters was the director of Idaho National Laboratory and president of Battelle Energy Alliance, LLC. He was responsible for the management and integration of a large, multipurpose laboratory whose mission focuses on nuclear energy, national and homeland security, and energy and environmental science and technology. Peters served 2 years as chairman of the National Laboratory Directors' Council, an independent body that coordinates initiatives and advises the DOE and other national laboratory affiliates. Prior to joining Battelle, he served as the associate laboratory director for Energy and Global Security at Argonne National Laboratory. Peters serves as a senior adviser on nuclear energy technologies, research and development programs, and nuclear waste policy. As an expert in nuclear fuel cycle technologies and nuclear waste management, he is often called upon to provide expert testimony to Congress and to advise in formulation of policies for nuclear fuel cycles, nonproliferation, and nuclear waste disposal. Peters was honored as a fellow of the American Nuclear Society (ANS) for outstanding accomplishments in nuclear science and technology. He served on the ANS Public Policy Committee, the executive committee of the ANS Fuel Cycle and Waste Management Division. Peters serves on several boards and advisory committees, including the Idaho Power Board. He has received extensive management and leadership education and training, including completion of the Strategic Laboratory Leadership Program at the University of Chicago Booth School of Business. Peters received a BS in geology from Auburn University and a PhD in geophysical sciences from the University of Chicago. He is an elected member of the National Academy of Engineering.

SUSAN J. SIMKINS (formerly Susan Mohammed) is a professor of industrial-organizational psychology at The Pennsylvania State University, where she leads the Teams, Cognition, and Time lab. As the director of team science for the Penn State Clinical and Translational Science Institute, she merges science and practice by educating and consulting with team leaders and members on improving their team processes and outcomes. For the past three decades, Simkins has investigated the drivers of effective teamwork and performance. Her research focuses on team cognition, team composition/diversity, and the role of time in team and leadership research, and her most recent work is applying these research topics to human-robot teaming. The National Science Foundation, the National Institutes of Health, and the Office for Naval Research fund Simkins' research, and she is a fellow of the Association of Psychological Science and the Society for Industrial and Organizational Psychology. She serves as an associate editor for the *Academy of Management Annals* and the *Journal of Business and Psychology*. Simkins received her PhD from The Ohio State University.

KELLY D. TAYLOR is an assistant professor of medicine in the Division of Prevention Science and director of the Center for Pandemic Preparedness and Response in the Institute for Global Health Sciences at the University of California San Francisco. Her research aims to both train leaders in health equity science and build transformative public health solutions with community partners to advance equity and saves lives by centering the perspective of those individuals and communities who are experiencing risks for poor health outcomes and empowering both them and their care teams to optimally mitigate that risk. As a part of that work, Taylor leads Combating Unequal Treatment in Healthcare Through Virtual Awareness and Training in Empathy, which is a team science developed study that explores decreasing bias in health care experienced by Black, Indigenous, and People of Color using patient-provider virtual reality simulations. She was invited to speak at the 2023 Congressional Black Caucus's Legislative Conference on Unmasking Bias in Medicine. Taylor was awarded National Institutes of Health pre-doctoral and postdoctoral traineeships to study health services research and AIDS prevention studies respectively. She holds degrees from the University of Michigan, Vanderbilt University, and the University of California, Berkeley.

CORY VALENTE is the senior human resources director of talent acquisition and the corporate director for the office of inclusion at the Dow Chemical Company. He is responsible for developing and implementing strategies and best practices to advance an inclusive workplace culture and to position Dow to attract, recruit, and retain a skilled and engaged workforce to deliver against the company's strategic priorities. Previously, Valente served on a business leadership team as a research and development (R&D)/technical service and development director responsible for developing and implementing an innovation strategy to fuel business growth through more sustainable processes and products. Since joining Dow, his career has been at the intersection of innovation and workplace culture, serving in a diverse range of roles of increasing responsibility in R&D, human resources, and the office of inclusion. Valente is the author of more than 25 peer-reviewed publications in the chemical sciences. He holds a PhD in organic chemistry from York University and completed a postdoctoral fellowship with 2016 Nobel Laureate in Chemistry Sir Fraser Stoddart at Northwestern University.

CHRISTOPHER W. WIESE serves as an assistant professor in the School of Psychology and the area director of the Industrial-Organizational Psychology Program. He is also a prominent board member of the International Network for the Science of Team Science and the Team Science Lead for the Georgia Clinical and Translational Science Awards Program. Previously, Wiese held various roles that have honed his expertise in organizational psychology and team dynamics. An expert in team science, he specializes in studying team resilience, learning, and the temporal dynamics of team phenomena. Wiese has conducted numerous workshops and consulting sessions on team composition, conflict management, team effectiveness, and leadership. His innovative Team Science Boot Camp is a testament to his commitment to advancing team science methodologies, and his distinguished work has been sponsored by prestigious institutions such as the National Science Foundation, National Institutes of Health, National Aeronautics and Space Administration, and the Air Force Research Laboratory, highlighting his significant contributions to the field. Wiese received his PhD in industrial-organizational psychology from the University of Central Florida.

Appendix B

Team Science Background

TEAM SCIENCE AND CROSS-DISCIPLINARY COLLABORATIONS: DEFINITION AND EVOLUTION

The scholarly study of science has a long tradition with a set of foundational fields going back decades. In this section, the committee briefly describes how science has been studied as a scholarly area of inquiry. The committee then transitions to one of the newer fields of study science, the science of team science. In this context, the committee provides important definitions to help scaffold our discussion and briefly describe the differing forms of cross-disciplinary collaborations that can occur in team science.

Studying Science and Scientists

One of the earliest fields to study science is "the history and philosophy of science" (Pinnick & Gale, 2000). This field has a long tradition of scholarly work examining science and medicine through a historical lens. Taking a broad perspective, it examines how the understanding of the natural world has changed over the centuries and how scientific innovation affects society culturally, economically, and politically. Similar, but more narrowly focused, is the field of "social studies of science" (e.g., Nola, 2013; Woolgar, 1991) and the closely aligned field, "science and technology studies" (Hackett et al., 2008). Both examine how science affects society with an emphasis on the social dimensions of science and the role and ethical implications of science and technology.

Taking a more quantitative approach, the field of "scientometrics" was born out of a need to better measure and analyze science, technology, and innovation. From its origins, it relied heavily on bibliometrics and citation analyses to understand scientific impact and map scientific fields (de Solla Price, 1981; Garfield, 2009; Lane, 2009; Leydesdorff et al., 2018). Out of this came a more practice-oriented study of science, called "science of science policy" (Fealing, 2011). Through a blend of quantitative data and qualitative information, the science of science policy seeks to develop a more quantitatively informed basis for science policy and works to develop models that can help guide investments in science. These have evolved into a related area of study known as the "science of science." This field is a blend of scientometrics, network science, and big data analytics. The goal is both to improve the understanding of how knowledge is produced and disseminated and to make recommendations for improving the scientific ecosystem (Fortunato et al., 2018).

The aforementioned areas of study all examine different concepts, processes, and outcomes associated with science. Some fields study science to add to our understanding while others also seek out ways to improve the scientific ecosystem. To varying degrees, each field has also sometimes studied collaboration in science but rarely make it a focal issue of inquiry. Because of this, the science of team science (Hall et al., 2008) was specifically developed as a scholarly examination of teamwork in science. The goal of the science of team science is to improve the understanding of how scientists interact as members of a team, and how their collaboration helps build and integrate knowledge across disciplinary, professional, and institutional boundaries (Stokols et al., 2008). From this improved understanding, the science of team science aims to help science teams make full use of their intellectual capacity (Salazar et al., 2012). The science of team science fundamentally reframes science collaboration as a process of teamwork to be mastered (Fiore, 2008). In contrast to the other studies of science, teams are the focal area of study in the science of team science to improve our fundamental understanding of the collaborative production of knowledge and to develop new methods and models to improve science teamwork (National Academy of Sciences, 2005).

Some recent studies of collaboration in team science focus on large-scale projects across multiple teams and multiple universities and countries. One of these is "big team science" (Baumgartner et al., 2023; Coles et al., 2023), which is a recent community of researchers conducting complex collaborations where teams of scientists representing dozens of labs around the world are collaborating on related projects. These initiatives were undertaken to increase the robustness of research in what has traditionally been small sample studies, and big team science has made important progress in bringing teams together to study a variety of scientific issues. To accomplish this, big team science recruits dozens of laboratories from around the world, asking each to run identical studies to increase samples to an order of magnitude larger than is typically found (e.g., social science experiments might have several dozen participants, but big team science studies can have several thousand; Coles et al., 2022). However, in doing so, they face both longstanding and novel challenges when it comes to coordinating collaboration (see Coles et al., 2023). Primarily out of Australia, the scholarly study of a particular form of translational science has emerged, referred to as integration and implementation sciences at Integration and Implementation Insights (i2Insights).[1] i2Insights, or I2S, is both a community of practice as well as a clearinghouse for material developed to improve collaboration in complex scientific areas. Focusing on methods, frameworks, and concepts for addressing complex societal and environmental issues, i2Insights seeks to publish and share a variety of research developments in areas such as climate change while attending to varied interdisciplinary approaches (e.g., systems thinking, action research, sustainability science). i2S is a form of convergence research that brings together differing approaches for studying and improving significant societal and environmental problems (NRC, 2014).

Developed primarily by the Swiss Academies of Arts and Sciences, the Network for Transdisciplinary Research (td-net[2,3]) is a repository of resources that are designed to support collaborative problem solving when team members come from different fields.

Definitional Distinctions in Team Science

To discuss these complex forms of collaboration, the committee finds it necessary to define several key terms regarding teamwork in science. First, the committee defines *team science* as collaborative, interdependent research conducted by more than one individual. Most shared publications were published by science teams of approximately two to ten members (Wuchty et al., 2007). Second, the committee also recognizes that there are often larger groups of more than ten scientists collaborating on complex problems (e.g., astrophysics), and publications produced by hundreds to even thousands of co-authors are becoming more prevalent (Nogrady, 2023). Nonetheless, these larger groups often experience the same challenges when interacting. Last, when trying to address what counts as

[1] More information about Integration and Implementation Insights can be found at https://i2insights.org/about

[2] More information about the Network for Transdisciplinary Research is available at https://transdisciplinarity.ch/

[3] The td-net toolbox is available at https://naturalsciences.ch/co-producing-knowledge-explained/methods/td-net_toolbox

success for these teams, the 2015 National Academies committee simply considered effectiveness to mean achieving team goals and objectives (National Research Council, 2015). However, the 2015 committee also acknowledged that there are multiple collaborative processes that can be assessed to understand what leads to effectiveness (National Research Council, 2015).

Team science is an increasingly critical area of inquiry given that modern science, more and more, embraces research ideas that cross disciplines. Therefore, team science varies in form, since disciplinary differences and integration can vary. Specifically, team science can vary in the degree in which members are integrating concepts, techniques, and theories from different fields. To provide additional definitional grounding, the committee chose to briefly describe how these collaborations can vary. While there are differing views in the literature and varying approaches internationally, our aim was to offer definitions that encompass the key elements found in the approaches that cross disciplines. For further exploration, refer to the works of Klein (2010), Wagner et al. (2011), Hall et al. (2012), National Academies (National Academy of Sciences et al., 2005), National Research Council (NRC; 2014, 2015), and Stokols et al. (2008).

The first type of cross-disciplinary research is multidisciplinarity. Multidisciplinarity involves collaboration among multiple disciplines toward a shared objective. These types of studies aim to facilitate a comprehensive analysis of the research issue. In multidisciplinary research, scientists may work on their own, in parallel, or sequentially. In doing so, they may convene periodically to exchange what they have accomplished and discovered. While each discipline's contributions complement each other, their methods, concepts, and theories are typically not integrated. Additionally, individual scientists remain ensconced in their own forms of disciplinary perspectives.

The next form of cross-disciplinary research is interdisciplinarity. Unlike the mere complementarity found in multidisciplinary research, this approach requires scientists to blend or juxtapose concepts and methods from various disciplines. The main goal is the systematic integration of information, data, techniques, tools, perspectives, concepts, and/or theories from multiple disciplines or bodies of specialized knowledge (National Academy of Sciences et al., 2005). The objective of interdisciplinarity is to provide a more integrated and fundamental understanding of the subject matter by addressing problems that exceed the boundaries of any one discipline.

A more deeply integrated research approach is transdisciplinarity. What distinguishes this approach is its advancement of discipline-specific theories, concepts, and methods (Hall et al., 2008). Moreover, it often requires considering problems across various levels of analysis (e.g., individual, group, community). In doing so, transdisciplinarity often involves "translational" partners from diverse sectors of society (e.g., nongovernmental organizations, community, industry) in the research process. These translational partners typically include individuals outside science, such as community members, to provide real-world insights while also improving the likelihood of translation. Overall, transdisciplinary research aims to cultivate a holistic understanding of the examined problem (Hadorn et al., 2010). Because of its deeply integrated nature, transdisciplinary research primarily concentrates on societal issues and the generation of actionable knowledge (Brandt et al., 2013). When defining their research process, transdisciplinary teams focus on problem identification, structuring, and analysis (Pohl & Hadorn, 2008). More specifically, transdisciplinary research becomes essential when there is uncertainty surrounding scientific knowledge about a significant problem domain, when the specific characteristics of problems are unclear or open to interpretation, and when there are significant stakes for those affected by these problems. In these types of situations, transdisciplinary research is able to address problem domains in a manner that enables better comprehension of the intricacies of the problem and deeper consideration of different perspectives on problems. Transdisciplinary teams are able to consider social and scientific perspectives while working to establish connections between theoretical and context-specific knowledge to build new knowledge and practices.

KEY TAKEAWAYS FROM THE REPORT: *ENHANCING THE EFFECTIVENESS OF TEAM SCIENCE*

From 2013 to 2015, the National Academies' Committee on the Science of Team Science worked on a report to offer research-based guidance aimed at enhancing the processes and outcomes of collaboration in science (NRC, 2015). This project was supported by the National Science Foundation (NSF) and by Elsevier. The overarching objective was to improve the effectiveness of collaboration within science teams, research centers, and institutes. The audience for the report ranged from the NSF and other public and private sources of research funding to the broader scientific community, research centers, institutes, and universities.

This committee's charge was to conduct a consensus study to recommend opportunities for enhancing the effectiveness of collaborative research and explore what factors impact team dynamics, effectiveness, and productivity. They were to investigate these factors at the team, center, or institute level to understand how they influence science team effectiveness. The committee was tasked with exploring different management approaches and leadership styles that influence effectiveness. They were also tasked to examine how tenure and promotion policies help or hinder academic researchers who participate in research teams. Finally, the committee was charged with considering the organizational factors (e.g., human resource policies, cyberinfrastructure) that might influence the effectiveness of science teams along with organizational structures, policies, and practices aimed at promoting effective teams.

At the outset, the 2015 National Academies committee identified a set of key features that pose challenges for science teams (NRC, 2015). The committee found that a high variety of membership within a team occasionally led to varying perspectives and approaches that could complicate collaboration. Relatedly, the committee discovered that there was a need for deep knowledge integration arising from the goal of merging disparate expertise and disciplinary backgrounds. Large science teams often face difficulties due to their size, making coordination and communication more complex. Misalignment of goals within and across science teams can hinder collaboration and cohesion within the broader research environment. Some science teams experience permeable boundaries that can result in ambiguity regarding roles and responsibilities or obscure the extent to which individuals should be contributing to the differing projects. Geographic dispersion was found to add another layer of complexity, requiring effective virtual communication and coordination mechanisms. Furthermore, high task interdependence necessitates close coordination and cooperation among team members to achieve shared objectives.

To address these challenges, the 2015 National Academies committee considered the broad body of literature and consulted experts from the social sciences to understand findings on teams and organizations. They concluded that there was a robust body of research going back decades showing how team processes related to team effectiveness. Furthermore, the committee identified a set of interventions that support teamwork and offer the most promising route to enhance team effectiveness. These included team composition, development, and leadership.

Regarding team composition, the committee found that research conducted in nonscience contexts indicated that the makeup of a team significantly impacts its effectiveness (NRC, 2015). This relationship depended on several factors, including task complexity, level of interdependence among team members, and duration the team was together. Task-relevant variety was an important factor affecting team effectiveness as it influenced membership. The committee noted that leveraging analytic methods developed in nonscience contexts, along with researcher networking tools established within scientific domains, could enable practitioners to more systematically attend to team composition. The committee suggested that scientists could use these tools to optimize team compositions to enhance overall effectiveness, while also considering task complexities, interdependencies, and the value of diversity (NRC, 2015).

Out of the above conclusions, the report recommended the use of task analytic methods and tools. These methods and tools assist in identifying requisite knowledge, skills, and attitudes, and they can help ensure that task-related differences align with team member experience and project requirements (NRC, 2015). Additionally, the committee suggested considering the application of tools like research networking systems, which were specifically designed to help with the assembly of science teams. Finally, they suggested future collaborations to help assess these methods to ensure their effectiveness and relevance in team science as well as provided guidance on how to improve them (NRC, 2015).

In the context of professional development for science teams, the committee noted that research outside of science has demonstrated that several types of interventions can improve team processes and outcomes. Recognizing this, the committee recommended that "team-training researchers, universities, and science team leaders should partner to translate, extend, and evaluate the promising training strategies shown to improve the effectiveness of teams in other contexts" (NRC, 2015, p. 8). Related, when considering educating scientists to work on teams, the committee found that "colleges and universities are developing cross-disciplinary programs designed to prepare students for team science" (NRC, 2015, p. 9). However, at that time, there had been scant empirical research on the extent to which students learn the targeted competencies and on whether their acquisition contributes to team science effectiveness.

Similarly, when considering leadership and team science, the committee found that decades of "research on team and organizational leadership in contexts other than science provide a robust foundation of evidence to guide professional development for leaders of science teams" (NRC, 2015, p. 9). From this, the committee recommended that "researchers, universities, and leaders of team science projects should partner to translate and extend the leadership literature to create and evaluate science leadership development opportunities" (NRC, 2015, p. 9).

Regarding research universities, the 2015 committee noted efforts to initiate and foster interdisciplinary team science, as seen by the establishment of research centers and institutes. However, the impact of these endeavors on the quantity and quality of team science remains largely unassessed. Relatedly, when considering reward structures within research universities, the committee concluded that promotion and tenure review policies typically lack "comprehensive, clearly articulated criteria for evaluating individual contributions to team-based research" (NRC, 2015, p. 11). Additionally, if criteria do exist, the recognition and rewards for team-based research vary significantly both within and across universities, potentially leading to disparities in incentives for participation (NRC, 2015). These inconsistencies may deter young faculty from pursuing team science in environments where such collaborations are undervalued. To address these issues, the committee recommended that universities and scholarly associations work to "develop and evaluate broad principles and more specific criteria for allocating credit to team-based work" (NRC, 2015, p. 11), so that promotion and tenure committees more accurately assess candidates and foster an environment conducive to team science.

The 2015 committee also noted that public and private funding agencies can play a pivotal role in cultivating a culture within the scientific community that promotes and facilitates team science. In addition to providing financial support, these agencies have the capacity to influence practices through the development of reports espousing the value and importance of team science, as well as providing training workshops. To further advance this culture of collaboration, the committee recommended that funders collaborate with the scientific community on several fronts (NRC, 2015). First, they "should encourage the development and implementation of new collaborative models, such as research networks and consortia" to facilitate interdisciplinary research efforts (NRC, 2015, p. 11). Second, funders can incentivize team science by helping to develop promotion and tenure policies that recognize and reward collaborative contributions. Third, they can allocate resources to support team science initiatives, such as establishing information repositories and offering training modules to enhance collaboration competencies. By actively engaging with the scientific community and implementing these recommendations, funding agencies can effectively promote and support the growth of team science.

The 2015 committee also considered additional ways funders can support the science of team science. They concluded that funding agencies generally lack consistency in how they evaluate scientific merit with collaborative merit, particularly concerning how teams execute the work. Often, agency announcements seeking team science proposals lack clarity regarding the expected level of collaboration and knowledge integration. To address these issues, the committee recommended funders mandate proposals for team-based research to include detailed collaboration plans (NRC, 2015). Additionally, funders can provide guidance to scientists on incorporating these plans into their proposals, along with criteria for reviewers to evaluate them effectively. Furthermore, authors of proposals for interdisciplinary or transdisciplinary research projects can be required to articulate how they will integrate differing disciplinary perspectives, concepts, theories, and methods. By implementing these approaches, the committee noted that funding agencies can help steward the development and evaluation of team science (NRC, 2015).

The 2015 committee concluded that for progress to be made in the science of team science, more efforts are necessary to assess and enhance the tools, interventions, and policies proposed in the report (NRC, 2015). However, there is a notable absence of funding programs dedicated to investigating the effectiveness of science teams. Considering this, the committee concluded that there needs to be support for fundamental research on team science to inform continuous enhancements in its effectiveness (NRC, 2015). Furthermore, the committee pointed to a set of inter-related challenges that complicate research on science teams. These include the multifaceted and sometimes competing goals of team science projects and the multilevel perspective required to study science teams and processes at individual, team, and organizational levels. To address these challenges and promote advancements in team science, the committee recommended that public and private organizations allocate funding to support research on team science effectiveness. Additionally, the committee called for support for ongoing evaluation and refinement of their recommended interventions and policies. The committee recommended future research be conducted not just on science teams but also on the role of scientific organizations, such as research centers, networks, and consortia in bolstering science teams and larger groups (NRC, 2015). Finally, the committee noted that collaboration with universities and the scientific community is crucial to facilitate researchers' access to team science personnel.

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Appendix C

High-Functioning Science Teams

What does a high-functioning, effective science team look like? According to Hackman (1987), team effectiveness is not just the product of collaboration; it is also a function of the social processes within a group and the personal satisfaction of its members. While the success of science teams is often measured through metrics such as research impact, successful grant applications, accepted journal publications, filed patents, and community connections, these outcomes alone do not reveal the processes that teams undergo to achieve these goals. In other words, they do not capture how the team functions on a day-to-day basis, such as team member behavior or their psychological states. It is crucial to understand both how teams function and what indicates that they are functioning well. For instance, if one attempts to improve a team based solely on outcome-based metrics, the only guidance they can provide is to enhance these metrics (e.g., secure more grants, file more patents).

Building on the foundation laid by the 2015 report *Enhancing the Effectiveness of Team Science* (National Research Council [NRC], 2015), this appendix aims to equip readers with an understanding of the mechanisms that underpin successful team science by illuminating the processes that contribute to the evolution of high-functioning science teams. First, the text explores how teams operate by offering two perspectives: a systems perspective and a temporal perspective. These perspectives will give the reader an understanding that teams neither operate in a vacuum, nor do they remain static over time. Subsequently, this appendix will highlight key indicators of successful scientific teamwork, providing a practical guide for identifying the components of effective scientific collaboration.

Before presenting these perspectives and indicators, it is necessary to first establish a shared understanding of terminology. Formally, a *science team* consists of two or more scientists working collaboratively toward a shared goal (NRC, 2015). In practice, science teams often include a diverse array of members, such as principal and co-investigators, research associates, postdoctoral fellows, graduate and undergraduate students, financial and administrative staff, and community members. The roles within science teams are often functionally complementary, contributing both directly (e.g., idea generation, experiment execution) and indirectly (e.g., processing annual reports, hiring postdoctoral fellows, purchasing research equipment) to the generation of new scientific knowledge.

Larger science teams may constitute a scientific "multiteam system"—in other words, interdependent networks of multiple component teams working toward broader objectives while maintaining their respective goals and responsibilities (Carter et al., 2019; Zaccaro et al., 2020). As an organizational form, the multiteam system structure is becoming increasingly prevalent, particularly in scientific endeavors, as it allows for exploring and investigating more complex challenges. Thus, science teams can be viewed as existing within a system composed of individuals, teams, multiteam systems, and institutes. This recognition of teams existing in a system is the first perspective to be discussed.

Importantly, teams are not static entities; they change and evolve over time. Although a team is technically formed once individuals are assigned to it, teams need time to develop and integrate psychologically before members fully consider themselves part of a cohesive unit. Therefore, it is crucial to understand that time is a key factor in how teams function (Cronin et al., 2011; Mohammed et al., 2008). Time not only influences the way teams operate but also provides valuable insights that can inform team science practices. For example, measuring trust immediately after a team is formed would be premature, as trust between team members develops over time (Grossman & Feitosa, 2018). Assessing a team too early would not yield an accurate understanding of trust within the team. Additionally, there are specific stages in a team's evolution where certain behaviors become particularly important. For instance, while communication is critical for success throughout the team's life cycle, clarifying roles and responsibilities is especially vital during the initial formation of the team (Kozlowski & Bell, 2007); see Chapter 3 in this report for a discussion of relevant best practices. Understanding these temporal dynamics is essential for fostering effective teamwork.

Much like the systems perspective, there are many ways in which time can be incorporated into understanding team functioning. One could take a team evolution or team development approach, which examines the stages or phases that teams go through as they get to know each other and work toward achieving their goals. For instance, Tuckman's five-stage model (Tuckman, 1965) outlines the stages of forming, storming, norming, performing, and adjourning, where teams move from initial formation and conflict to effective collaboration and eventual disbandment. This model highlights how team dynamics evolve over time, with each stage building on the previous one. Another classic model is the punctuated equilibrium model (Gersick, 1988, 1989), which suggests that teams experience periods of stability punctuated by significant shifts in behavior, often occurring midway through a project. These shifts lead to a more focused and productive second phase of work, emphasizing the impact of critical moments in team development. A last example is Kozlowski & Bell's (2007) process model of team compilation, which not only describes the stages teams go through (team formation, team compilation, role compilation, team compilation) but also where these processes occur (individual level, dyadic level, team level).

Performance episodes offer another way to apply a temporal lens to team dynamics. These episodes refer to distinct periods during which a team works toward specific objectives, often engaging in multiple episodes simultaneously, each with a different focus and duration (Marks et al., 2001; Weingart, 1997; Zaheer et al., 1999). These episodes can range from short-term cycles lasting a few hours or days to long-term cycles extending over months or even years. Short-term episodes might involve daily operations, problem-solving sessions, or completing specific sections of a project, while long-term episodes could encompass strategic planning, the development of complex initiatives, or the overall progression of a major project. The input-mediator-output-input (IMOI) model (Ilgen et al., 2005) is often applied to understanding performance episodes. This model describes team development as a cyclical process where inputs (e.g., team composition, resources) influence mediators (e.g., team processes, emergent states) that, in turn, affect outputs (e.g., team performance, member satisfaction). These outputs then become inputs for the next cycle, influencing subsequent team interactions and development. The IMOI model highlights the dynamic and iterative nature of team functioning, emphasizing that teams continually evolve through feedback loops and ongoing interactions.

In summary, understanding what makes a science team high functioning requires more than just measuring their outcomes. By exploring both systems and temporal perspectives, we can gain insights into what makes these teams effective and how effective teams operate. Whether building, developing, or evaluating science teams, understanding the context in which they exist (i.e., a systems approach) and how they evolve over time (i.e., a temporal approach) is crucial for achieving successful outcomes. In the following section, the systems approach will serve as the organizing framework, focusing on the key constructs and competencies at the individual, team, and multiteam system levels. Critically, as noted in Chapter 2, mid- to large-scale research on science teams has been limited in recent years. Therefore, this section draws on both small-scale research from the science of team science to more extensive studies from organizational sciences to highlight the most important constructs and competencies of high-functioning science teams.

FACTORS OF SUCCESSFUL SCIENCE TEAMS

It is crucial to acknowledge that a wide array of factors contribute to team success across various contexts. Extensive reviews and meta-analyses within the organizational sciences have identified numerous individual-, team-, and multiteam-level factors that predict team effectiveness. The discussion that follows will concentrate on the team- and multiteam-level factors most pertinent to the success of science teams. Discussion of individual-level factors can be found in Chapter 3.

Science Team-Level Factors

The effectiveness of a team is not solely determined by the individual characteristics of its members but also by the dynamics that occur at the team level. Two critical categories of team-level factors that significantly influence team success are team processes and team emergent states. Team processes refer to the specific behaviors and interactions that teams engage in as they work together, such as communication, coordination, and conflict (Mathieu et al., 2008). These processes are essential for ensuring that team members collaborate effectively and efficiently toward achieving their goals. On the other hand, team emergent states are conditions that develop over time within the team, such as trust, psychological safety, cohesion, and shared mental models (Mathieu et al., 2008). These emergent states are crucial for fostering an environment where team members feel safe to share ideas, take risks, and support one another. The following discussion will focus on the team processes and emergent states that are most vital to the success of science teams.

Team Learning Behaviors

Another important team behavioral process is team learning behaviors. Team learning behaviors refer to collaborative actions that contribute to either altering or reinforcing the team's shared understanding (Wiese & Burke, 2019) and are critically important to the success of science teams. This is particularly true in scientific contexts, where teams constantly integrate new information, adapt to evolving research findings, and synthesize different expertise. Science teams often operate in highly complex and dynamic environments, requiring them to collectively learn from both successes and failures to remain innovative and effective. These behaviors foster the team's ability to process and apply new knowledge, ensuring that the team is continually advancing its understanding and improving its approach to solving problems.

Much like communication, there are various forms of team learning behaviors. These are often categorized by where the learning occurs—either internal to the team, such as within discussions or task processes, or external to the team, such as gathering insights from outside sources. Additionally, team learning behaviors can be classified as exploitative, where the focus is on integrating existing knowledge and refining processes, or explorative, where the emphasis is on generating new ideas or gaining novel insights (Harvey et al., 2022). Regardless of the type, team learning behaviors are significantly related not only to team performance but also to the development of critical emergent states, such as psychological safety. This dynamic creates a positive feedback loop, as learning behaviors strengthen trust and cohesion, which, in turn, enhance the team's ability to continue learning and innovating.

Leadership

Leadership literature has evolved over the past few decades, indicating a shift from viewing leadership as an inherent trait of a single individual to understanding it as a set of behaviors or styles that can be exhibited by anyone on the team (Pearce & Conger, 2003; Pearce et al., 2008). This shift is especially relevant for science teams, where different expertise and perspectives are essential. In such teams, members with specialized knowledge may need to step up and demonstrate leadership at different points in time, depending on the demands of the project and the challenges faced. The dynamic nature of scientific work requires a flexible leadership approach that leverages the unique strengths of each team member.

While there are many different theories on leadership, the concept of shared leadership best captures the view of leadership as something that can be demonstrated by any team member. Shared leadership happens over time, and leadership roles are spread throughout the team. This concept can be understood through five key dimensions (D'Innocenzo et al., 2016). The first is the locus of leadership, which distinguishes between leadership that originates from outside the team (external) and leadership that comes from within the team (internal). The second dimension is the formality of leadership, which differentiates between leadership exercised by someone in a formal leadership role (e.g., a designated team leader) and informal leadership, where influence is exerted by individuals not explicitly tasked with leading.

A third dimension involves the distribution of leadership, which refers to how equally leadership roles are shared within the team. Some individuals view leadership as a collective process, where leadership responsibilities are shared equally by all members, while others see leadership as being distributed among members in varying degrees, with different individuals influencing the team in unique ways. Another important aspect of shared leadership is its temporal nature. Leadership within teams is not static; it shifts over time, with different members assuming leadership roles depending on the team's evolving needs and challenges. Finally, it is essential to recognize that leadership is not confined to a single set of behaviors. Leadership can range from traditional behaviors, such as decision-making and direction setting, to more task-oriented actions, such as organizing resources, facilitating collaboration, or providing support that helps the team achieve its goals. As mentioned earlier, the concept of shared leadership is particularly well suited for science teams, which typically consist of a group of experts with different expertise who contribute to the team's goals over an extended period of time. This variety creates opportunities for individuals to demonstrate their expertise and take on leadership roles at different stages of the team's life cycle. Shared leadership also has a demonstrated relationship with team performance.

Faultlines

One potential issue that can arise within science teams is the development of faultlines. Faultlines are divisions within a team that arise from differences between members, such as differences in expertise, discipline, or background (Jehn & Bezrukova, 2010; Thatcher & Patel, 2012; Thatcher et al., 2024). In science teams, faultlines are particularly important to consider due to the high likelihood of variety in expertise and functional roles. Science teams often consist of members from various disciplines, such as biologists, engineers, and social scientists, working together on complex problems. This variety, while essential for innovation and problem-solving, also increases the likelihood that faultlines will emerge, as differences in perspectives, knowledge, and approaches can create perceptual divisions within the team.

The impact of faultlines on team dynamics depends on whether they remain dormant or become activated. Dormant faultlines refer to the potential for division based on team composition, where members may recognize differences but do not yet act on them. In contrast, activated faultlines occur when these divisions become operational and influence team interactions, leading to subgroup formation and reduced cohesion. Faultlines typically become activated when the team faces challenges or stressors, such as conflicting goals, communication breakdowns, or perceived inequality in contributions, which exacerbate underlying differences and cause these divisions to surface.

Research has shown that activated faultlines are more detrimental to team functioning than dormant faultlines. While dormant faultlines may influence team conflict by creating an underlying tension, activated faultlines have far more significant consequences. They lead to increased conflict, reduced information sharing, lower team satisfaction, and ultimately, diminished team performance (Thatcher et al., 2024). In science teams, where collaboration and integration of different knowledge is critical, activated faultlines can severely hinder the team's ability to achieve its goals. Therefore, managing faultlines effectively is essential for maintaining team cohesion and ensuring the success of scientific collaborations.

Team Cognition

An essential indicator of a high-functioning science team is team cognition. Team cognition refers to the shared knowledge structures and patterns among team members that enable them to anticipate each other's needs and coordinate their actions efficiently (Mohammed et al., 2021). As team cognition involves the alignment and integration of individual cognitive states, it is classified as an emergent state, meaning that it evolves and strengthens over time through interaction and collaboration. There are two primary types of team cognition: shared mental models and transactive memory systems. Shared mental models refer to the common understandings that team members have about key aspects of their tasks, roles, and the environment in which they are working. Shared mental models enable team members to develop similar expectations, allowing for smooth coordination without the need for explicit communication at every turn (Van den Bossche et al., 2011). Transactive memory systems, on the other hand, refer to the division of knowledge within the team, where individuals not only know their specific areas of expertise but also understand who within the team holds particular knowledge (Mohammed et al., 2021). This system enables members to effectively locate and retrieve information by relying on the specialized knowledge of others.

For science teams, team cognition is particularly important, as these teams often consist of members with different disciplinary backgrounds and specialized expertise. The complexity of scientific work means that team members not only bring their knowledge to the table but also integrate and apply the knowledge of others. Shared mental models can help science teams align on project goals, methodologies, and expected outcomes, ensuring that all members are working toward a unified vision. Meanwhile, transactive memory systems allow team members to efficiently leverage the expertise distributed across the team, enhancing problem-solving and innovation.

However, achieving strong team cognition in science teams can be especially challenging due to the different perspectives and specialized knowledge each member brings. The process of building shared understanding and trust across different disciplines can be time-consuming, but it is critical for the team's overall success. Without effective team cognition, science teams may struggle with miscommunication, fragmented efforts, and missed opportunities for interdisciplinary collaboration. Therefore, fostering the development of shared mental models and transactive memory systems is essential to ensure that science teams can function cohesively and achieve their complex objectives.

Psychological Safety

Science teams are more likely to thrive when they foster a strong sense of psychological safety. Psychological safety is the collective perception within a team that reflects an interpersonal environment where members feel safe to take risks, share ideas, and engage in open dialogue without fear of negative repercussions (Edmondson & Lei, 2014; Frazier et al., 2017). In teams where psychological safety is high, individuals are more willing to voice concerns, offer unique perspectives, and admit mistakes, knowing that these behaviors will be met with support rather than judgment. This climate of openness and trust is particularly critical for science teams, where innovation, complex problem-solving, and continuous learning are essential.

In teams with high psychological safety, members engage in candid communication and are unafraid to challenge ideas or offer constructive criticism. They are more likely to embrace feedback and engage in productive conflict, which fosters greater learning and collaboration. For science teams where interdisciplinary work often requires the integration of different knowledge sets and expertise, psychological safety allows team members to propose new approaches and solutions without the fear of embarrassment, a condition which is necessary for bringing together people from different thought worlds. In this environment, team members feel empowered to push boundaries and provide their unique perspectives, knowing that their contributions will be valued even if they challenge the status quo.

Research has consistently demonstrated the positive impact of psychological safety on team dynamics and outcomes. Studies have shown that psychological safety enhances team learning behaviors, promotes knowledge sharing, and encourages creative problem-solving (Edmondson & Bransby, 2023). Additionally, psychological safety mitigates potential negative effects of team differences by fostering greater cohesion and collaboration among members with differing perspectives. In the context of science teams, psychological safety serves as the foundation for effective collaboration, ensuring that teams can fully leverage their collective knowledge to achieve their scientific goals.

The effectiveness of science teams is not determined solely by individual characteristics but also by vital team-level factors. The behaviors these teams engage in (i.e., team processes) and the dynamics that manifest along the way (i.e., emergent states) are indicative of high-functioning science teams. Team processes, such as communication, coordination, and conflict management, represent the behaviors and interactions that enable teams to work together efficiently. These go together with the emergent states, including trust, psychological safety, and shared mental models that evolve over time, creating an environment where team members feel safe to share ideas and collaborate effectively. The processes and emergent states mentioned here are particularly important for science teams given their interdisciplinary nature and the complexity of their goals. There are many other processes and emergent states that contribute to successful teamwork across various domains. Ultimately, fostering both strong team processes and positive emergent states is crucial for ensuring that science teams can collaborate effectively and achieve their collective goals.

Multiteam System Factors

Much of what has been discussed so far has been well established since the publication of the previous report in 2015. Concepts such as team cognition, psychological safety, and the importance of shared leadership have long been recognized as critical components of high-functioning science teams. These factors contribute to the effective coordination of diverse expertise, the integration of knowledge, and the overall success of teams working toward complex goals. However, one area of research that has advanced significantly since the last report is the study of multiteam systems. Multiteam systems, which involve multiple interdependent teams working together to achieve a shared superordinate goal, have become increasingly relevant in the realm of scientific research (Zaccaro et al., 2020). A complementary development is the exponential growth in the use of multiteam systems within the scientific community, as evidenced by the rise of large-scale initiatives such as Science and Technology Centers (STCs) and Engineering Research Centers (ERCs).[1] These centers are built on the principle of cross-disciplinary collaboration, bringing teams together from various fields and institutions to tackle complex scientific and technological challenges. Given this shift, it is crucial to examine the specific attributes of multiteam systems that contribute to the success of their scientific endeavors. Understanding

[1] For more information on STCs and ERCs, see https://www.nsf.gov/od/oia/ia/stc and https://www.nsf.gov/eng/engineering-research-centers

these factors—such as boundary status, component team distance, and the type of superordinate goals—will allow better assessment of what drives high performance in science multiteam systems and how these teams can be supported and structured to maximize their impact on research and innovation.

Multiteam System Attributes

Much like the previous section, which focused on individual- and team-level factors associated with high-functioning teams, the first aspect of a multiteam system that will be discussed are the key characteristics of the multiteam system itself. These characteristics are critical because they shape how teams within the system interact, coordinate, and ultimately achieve their shared objectives. In the context of science multiteam systems—multiteam systems composed of science teams—understanding these characteristics is important for ascertaining the most critical processes to focus on when developing and evaluating a science multiteam system. The three primary characteristics of multiteam systems that will be discussed are boundary status, component team distance, and superordinate goal type. Each attribute plays a distinct role in influencing the effectiveness of the scientific multiteam system.

Boundary status refers to whether the teams within the multiteam system come from within a single organization (internal boundary status) or across multiple organizations (external boundary status). Internal multiteam systems tend to operate under a shared set of norms, communication protocols, and authority structures, which can facilitate coordination and collaboration. On the other hand, external multiteam systems, composed of teams from different organizations or institutions, often face more challenges in aligning their goals, managing resources, and navigating different organizational cultures. For example, Kotarba et al. (2023) found that in a multi-institutional cross-disciplinary translational team focused on long COVID-19 research, teams from different universities faced challenges in coordinating efforts due to their external boundary status. Each institution had different operational norms and patient populations, which complicated collaboration and goal alignment across the team. For science multiteam systems, which often involve teams from multiple institutions (e.g., universities, research centers), understanding the boundary status is crucial, as it helps to anticipate challenges related to communication, trust-building, and the harmonization of different institutional priorities, all of which are vital for the success of large-scale interdisciplinary projects (Zaccaro et al., 2020).

The second attribute, component team distance (CTD), refers to the geographical, cultural, functional, or disciplinary distance between the teams that make up the multiteam system. In high CTD systems, teams are more likely to face challenges in coordinating efforts due to physical separation, differences in disciplinary languages, or contrasting cultural norms. For scientific multiteam systems, CTD can be particularly relevant because science teams often work across institutions, regions, and even countries, introducing significant logistical and communication challenges. High CTD can also exacerbate misunderstandings or delays, slowing research progress or hindering collaboration. For example, Ingersoll et al. (2024) demonstrated the complexities of conducting a multisite clinical trial using virtual multiteam systems, where geographically dispersed teams had to navigate communication barriers, time zone differences, and coordination issues to maintain fidelity and progress in data collection. However, understanding CTD can also help teams develop strategies for bridging these divides, such as paying special attention to developing communication norms, creating cross-team coordination roles, or holding regular in-person meetings to strengthen relationships and align goals.

The final attribute to consider is the superordinate goal type, which refers to the overarching goal all teams within the multiteam system are working toward. Superordinate goals in multiteam systems can generally be classified as either intellectual or physical. Intellectual goals involve generating knowledge, such as developing new theories or conducting scientific research, while physical goals may include building a tangible product or implementing a solution. In multiteam systems, it is crucial that teams not only focus on their individual or team-specific goals but also recognize how their contributions align with and support the broader system-level objective. As Carter et al. (2019) emphasize, one of the key features of multiteam systems is the hierarchical structure of goals, where component teams have both local (subordinate) goals and shared (superordinate) goals. Aligning these goals is essential for the system's success, as misalignment can lead to internal tensions, competition, or even conflict between teams, which can undermine the overall performance of the multiteam system. Ensuring that teams remain focused on the broader objective while pursuing their local goals is a balancing act that requires careful management (Shuffler et al., 2015).

Crucial Multiteam System Indicators

Beyond the structural components of multiteam systems, behavioral processes and emergent states play a critical role in determining their overall effectiveness. Many of these factors have been discussed in the previous section, such as communication, team cognition, and psychological safety, which are essential for team success at the multiteam level (Shuffler & Carter, 2018; Zaccaro et al., 2020). However, these elements take on added complexity at the multiteam system level, where coordination and collaboration occur not just within teams but also across multiple teams. While many of the core team-level components remain relevant, there are unique considerations specific to multiteam systems, especially within the scientific context. In the following section, three critical factors that are indicative of science multiteam system effectiveness are highlighted: boundary spanners, who facilitate cross-team communication and bridge organizational divides; inter-team coordination, which ensures the alignment and integration of outputs across teams; and balancing countervailing forces, which helps maintain system cohesion while allowing individual teams to achieve their specific objectives.

A crucial component of high-functioning, effective science multiteam systems is boundary spanners. Boundary spanners are individuals who facilitate communication and coordination across the boundaries between different teams, especially when those teams come from different disciplines, organizations, or geographic locations. They are particularly important in complex multiteam system structures, such as those with high CTD or external boundary status, where teams face greater challenges in aligning goals, managing cultural differences, and coordinating tasks. This can be seen in the challenges and recommendations provided by Kotarba et al. (2023). Boundary spanners help bridge gaps between teams by facilitating information exchange, trust-building, and alignment of objectives, which are crucial for maintaining system-wide cohesion (Carter et al., 2019; Zaccaro et al., 2020). Importantly, boundary spanners operate at both the component team level and the multiteam system level—coming not only from leadership but also from team members who help manage interdependencies across the system.

The boundary spanner role is critical for the success of science multiteam systems because it ensures that teams can collaborate effectively despite differences in expertise, institutional/organizational norms, and goals. Boundary spanners help manage the complex dynamics inherent in interdisciplinary and multi-institutional projects, ensuring that communication and information flow freely and that teams are aligned toward the multiteam system's superordinate goals. For instance, boundary spanners likely play important roles in large-scale, federally funded projects such as STCs and ERCs, where teams from various institutions collaborate to solve complex, multidisciplinary challenges. In these projects, boundary spanners facilitate collaboration between laboratories working on different aspects of the center's overarching goal, such as combining expertise in artificial intelligence with domain-specific knowledge like climate science or engineering. They help ensure that research findings from one team are effectively integrated into the work of other teams and that all teams remain aligned with the overarching center objectives. In science multiteam systems, where research teams from different fields or institutions collaborate to address complex problems, boundary spanners ensure that these collaborations are productive and not hindered by miscommunication or misalignment.

Relatedly, another component of high-functioning science multiteam systems is their ability to coordinate each component team within their system. Inter-team coordination refers to the processes by which teams manage interdependencies and synchronize their activities to achieve both their own goals and the system's superordinate goals (Ziegert et al., 2022). High-functioning multiteam systems require coordination both within and between teams, which may involve shifting focuses over time as projects evolve (Zaccaro et al., 2020). Early on, multiteam systems may prioritize task allocation and communication protocols, but as time progresses, coordination shifts toward aligning outputs and integrating efforts across teams. Ensuring that there is alignment between superordinate and subordinate goals facilitates effective inter-team coordination, as teams can see how their efforts contribute to the broader objectives.

Inter-team coordination is critical for the success of science multiteam systems because it enables teams to work in parallel while ensuring that their outputs are integrated into a cohesive whole. Returning to the example of STCs and ERCs, in these large, federally funded initiatives, teams with specialized expertise often address different facets of a complex problem. For instance, one team might focus on developing computational models that simulate neural circuits responsible for visual processing, while another team conducts experimental studies on how the brain processes social intelligence. Without effective inter-team coordination, these efforts could remain siloed, preventing the full integration of computational insights with biological data. However, when coordination mechanisms are in place, the contributions of each team—whether focused on machine learning, neuroscience, cognitive science, or any other scientific field—are aligned and complement one another, leading to scientific progress aligned with the STC's or ERC's superordinate goals.

Lastly, a unique element of effective science multiteam systems is balancing countervailing forces. High-functioning multiteam systems pay special attention to the unique needs of both the component teams and the overall multiteam system. Something that may be good for a single team, such as increasing cohesion or prioritizing its own goals, can sometimes detract from the performance of the entire multiteam system (Carter et al., 2019). For example, promoting strong cohesion within one team might reduce its willingness to collaborate with other teams, leading to silos and reduced system-level performance. Similarly, focusing too much on local team goals can result in a misalignment with the superordinate goals of the multiteam system, undermining the overall success.

Balancing these forces is critical for the success of science multiteam systems because it ensures that the system can leverage the strengths of each team while maintaining a focus on system-wide objectives. In the case of large, interdisciplinary initiatives like Clinical and Translational Science Awards, where teams often come from different fields with distinct goals and priorities, balancing these forces is essential for integrating different perspectives and achieving the broader research objectives.[2] For example, one team may focus on clinical trial design while another works on community engagement. Without careful management, these distinct priorities could lead to misalignment or competition for resources. However, by balancing the needs of individual teams with the overall goals of the multiteam system, the system can capitalize on the unique expertise of each team while ensuring progress toward the shared mission.

High-functioning science multiteam systems can take many forms, shaped by factors such as boundary status, component team distance, and the nature of the superordinate goal. These elements play a critical role in determining how teams interact, navigate logistical and disciplinary differences, and align their goals to drive the collective success of the system. Equally important are the processes and emergent states that support these interactions, such as boundary spanning, inter-team coordination, and balancing competing priorities, which together define a high-functioning science multiteam system. Despite the importance of these attributes and processes, empirical research specifically focused on scientific multiteam systems remains relatively limited, with a few notable exceptions (e.g., Kotarba et al., 2023). This gap is unfortunate given the increasing prevalence of large-scale scientific initiatives, such as STCs and ERCs, which have immense potential to advance scientific discovery and innovation.

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[2] For more information about Clinical and Translational Science Awards, see https://ncats.nih.gov/research/research-activities/ctsa.

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Appendix D

Sampling of Survey-Based Team Assessments

Table D-1 provides a sampling of survey-based assessments used in the team literature, including a construct/scale description, measurement specifics (number of items, dimensions, rating scale), and references indicating scale development and validation evidence.

TABLE D-1 Sampling of Survey-Based Team Assessments

Construct/Scale Name	Construct Definition/Scale Description
What Individual Characteristics Describe Your Team?	
To what extent are team members positioned for effective teamwork?	
Beliefs About Groups (BAG)	Beliefs about whether groups are desirable and effective
Team Role Experience and Orientation (TREO)	Predisposition to occupy different team roles
Multidimensional Perceived Person–Group Fit (MPPGF)	Fit between individuals and the group is measured on several dimensions including: • Needs–supplies match • Shared interests • Perceived demographic similarity • Complementary attributes • Values congruence • Goals similarity • Common workstyle
Are team members ready for team and cross-disciplinary collaboration?	
Research-orientation scale	Indicator of collaboration readiness that assesses team members' values and attitudes toward cross-disciplinary research on a continuum including unidisciplinary, multidisciplinary, and interdisciplinary/transdisciplinary research orientations

Measurement Specifics	Scale Development/ Validation Evidence
16-item BAG scale assessing 4 dimensions: preference for group versus individual work, positive group performance beliefs, negative group performance beliefs, and beliefs that others will work hard on group tasks. Items were rated on a 5-point scale ranging from strongly disagree (1) to strongly agree (5)	Karau et al. (2009)
48-item scale measuring members' propensities to occupy six different team roles, including: • Organizer • Doer • Challenger • Innovator • Team builder • Connector Rated on a 5-point scale (1=not at all; 5=to a very great extent)	Mathieu et al. (2015b)
28-item scale with 4 items each of the following 7 subscales: needs–supplies match, shared interests, perceived demographic similarity, complementary attributes, values congruence, goals similarity, and common workstyle. The extent to which the person performing the self-assessment agrees with the fit-related items is rated on a 5-point Likert scale (1=strongly disagree, 5=strongly agree)	Li et al. (2018)
10-item scale assessing team members' proclivity toward unidisciplinary (3 items, "researchers use theories and methods from a single discipline"), multidisciplinary (2 items, "researchers work in parallel or sequentially from disciplinary-specific base to address a common problem"), and interdisciplinary/transdisciplinary research orientations (5 items, "researchers work jointly but still from disciplinary-specific basis to address common problem" and "researchers work jointly using shared conceptual framework drawing together disciplinary-specific theories, concepts, and approaches to address common problems"; Rosenfield, 1992, p. 1351). Items rated on a 5-point scale ranging from strongly disagree to strongly agree	Hall et al. (2008) Rosenfield (1992)

continued

TABLE D-1 Continued

Construct/Scale Name	Construct Definition/Scale Description
Interdisciplinary Perspectives Index (IPI)	Attitudes toward working with team members from different fields and beliefs about the outcomes of cross-disciplinary work
Transdisciplinary Orientation Scale	"Values, attitudes, beliefs, conceptual skills and knowledge, and behavioral repertoires that predispose an individual to collaborating effectively in cross-disciplinary science teams" (Misra et al., 2015, p. 1)
What Are the Shared Affective, Cognitive, and Behavioral States in Your Team?	
How strongly do team members connect with each other and the team's purpose emotionally and attitudinally?	
Team cohesion	Interpersonal/social cohesion: emotional bonding among team members, reflecting trust, mutual respect, and camaraderie. Task cohesion: shared commitment to the team's mission that reflects dedication and responsibility to complete tasks and solve problems
Team trust	Trust is defined as a latent variable resulting from 2 distinct but related formative indicators (propensity to trust and perceived trustworthiness), which lead to 2 reflective and behavioral indicators (cooperation and monitoring) between team members
Perceived collective efficacy	Team members' perceptions of the group's ability to succeed
Collective team identification	Members' emotional commitment to the team and its goals
To what extent is team knowledge shared and differentiated in your team?	
Referee Shared Mental Models Measure (RSMMM)	The extent to which team members believe that they share a similar understanding of taskwork (what the team is doing) and teamwork (how the work gets done and who accomplishes what)

Measurement Specifics	Scale Development/ Validation Evidence
6-item scale assessing attitudes about cross-disciplinary work, including the extent to which they value interdisciplinary work, are optimistic about the scientific outcome of such work, have tolerance of and open-mindedness toward research perspectives other than their own, use multiple research methods from many disciplines, believe that a high degree of goodwill exists among their research collaborators, and believe that the benefits of interdisciplinary research outweigh the inconveniences	Misra et al. (2009)
12-item scale to measure team members' transdisciplinary orientation on two dimensions: (a) values, attitudes, and beliefs (6 items) and (b) conceptual skills and behaviors (6 items) on a 5-item Likert scale ranging from strongly disagree to strongly agree	Misra et al. (2015)
6-item scale measuring interpersonal (3 items) and task-oriented (3 items) team cohesion on a 1–7 Likert-type scale	Mathieu et al. (2015a)
21-item multidimensional measure with 4 dimensions, including (a) propensity to trust (6 items), (b) perceived trustworthiness (6 items), (c) cooperation (6 items), and (d) monitoring between team members (3 items) rated on a 7-point scale ranging from 1=completely disagree to 7=completely agree	Costa and Anderson (2010)
4-item scale rated on a 5-point scale (1=never, 5=most of the time)	Salanova et al. (2003)
4-item scale rated on a 7-point scale (1=completely disagree, 7=completely agree)	Van Der Vegt and Bunderson (2005)
13-item measure assessing whether team members believe they are on the same page about relevant team knowledge, including decision-making, technology, procedures, interactions, and priorities. Items are rated on a 7-point Likert scale (1=totally disagree, 7=totally agree)	Sinval et al. (2020)

continued

TABLE D-1 Continued

Construct/Scale Name	Construct Definition/Scale Description
Transactive memory systems scale	Unique member expertise plus a shared awareness of who knows what in the team
Team learning	The process through which team members collectively acquire, share, and apply knowledge to achieve common goals
How strongly do team members depend on each other and share the workload?	
Task interdependence	The degree to which team members rely on one another to complete their tasks and achieve the team's goals
Workload sharing	Equitable distribution of tasks and responsibilities among team members to ensure that the overall workload is managed efficiently and fairly
What Is the Quality of Team Processes and Interactions in Your Team?	
Conflict	Task conflict involves differences among team members about the content and outcomes of the tasks being performed Relationship conflict refers to personal incompatibilities among team members and is characterized by tension and animosity between team members Process conflict centers on issues about logistics, the procedures used to accomplish tasks, and who will perform what roles
Conflict management	Strategies and processes used to resolve disputes among team members in a constructive manner
Team processes	Team processes capture interaction between team members. Transition processes: teams engage in evaluation and planning activities Action processes: teams perform activities that directly contribute to goal attainment Interpersonal processes: teams foster motivation, manage emotions, and resolve conflict
Implicit coordination	The process by which team members align their actions and synchronize their efforts without explicit communication

Measurement Specifics	Scale Development/ Validation Evidence
15-item scale divided into 3 dimensions (specialization, credibility, and coordination) of 5 items each and rated on a 5-point Likert scale (1=strongly disagree, 5=strongly agree)	Lewis (2003)
7-item scale rated on a 5-point Likert scale (1=never, 7=always)	Edmondson (1999)
5-item scale rated on a 5-point Likert scale (1=strongly agree, 5=strongly disagree)	Van Der Vegt et al. (2000)
3-item scale rated on a 5-point scale (1=strongly disagree, 5=strongly agree)	Campion et al. (1993)
9-item scale with 3 sub-scales of 3 items each (task conflict, relationship conflict, and process conflict) rated on a 7-point Likert scale (1=not at all, 7=a lot)	Jehn and Mannix (2001)
4-item scale rated on a 7-point Likert-type scale (1=strongly disagree, 7=strongly agree)	Tekleab et al. (2009)
50-item full scale (15-item transition processes scale with 3 sub-scales (mission analysis, goal specification, strategy formulation); 20-item action processes scale with 4 sub-scales (monitoring progress toward goals, systems monitoring, team monitoring and backup, coordination); 15-item interpersonal process scale with 3 sub-scales (conflict management, motivating and confidence-building, affect management) 30-item shorter form 10-item shorter form	Mathieu et al. (2020)
4-items rated on a 5-point scale (1=extremely inaccurate, 5=extremely accurate)	Fisher et al. (2012)

continued

TABLE D-1 Continued

Construct/Scale Name	Construct Definition/Scale Description
Is the Climate in Your Team Supportive of Scientific Collaboration?	
Team climate	Collective perceptions and shared attitudes of team members regarding their team environment
Work group inclusion	The extent to which group members feel included in the team includes 2 dimensions: belonging (supportive and caring relationships among members) and uniqueness (differences between members are valued and respected)
Psychological safety	Shared belief among team members that the environment is safe for interpersonal risk-taking such that members can ask questions, admit mistakes, and raise concerns without fear of embarrassment or ridicule
Team Perceived Virtuality	"Shared affective-cognitive emergent state that is characterized by team members' co-constructed and collectively experienced 1) distance and 2) information deficits, thereby capturing the unrealized nature of the team as a collective system" (Handke et al., 2021, p. 626). Socio-constructivist perspective on team virtuality emphasizing how team members perceive virtuality
How Much Do Team Members Take on Different Leadership Roles in the Team?	
Team leadership	Influence across 2 main phases in the team life cycle: 1. Transition phase: planning the team's work and ensuring that taskwork and teamwork goals will be reached 2. Action phase: activities that contribute directly to goal accomplishment
Temporal leadership	The extent to which leaders schedule deadlines, synchronize team member behaviors, and allocate temporal resources

Measurement Specifics	Scale Development/ Validation Evidence
The Team Climate Inventory is a 14-item scale (short version) that measures team climate in the areas of vision, participative safety, task orientation, and support for innovation rated on a 5-point Likert scale (1=strongly disagree, 5=strongly agree)	Kivimaki & Elovainio (1999) Strating & Nieboer (2009)
The Work Group Inclusion scale is a 10-item scale rated on a 5-point scale (1=strongly disagree, 5=strongly agree)	Chung et al. (2020)
7-item scale rated on a 7-point scale (1=very inaccurate, 5=very accurate)	Edmondson (1999)
10-item scale with 2 dimensions: (a) collectively experienced distance (5 items) and (b) collectively experienced information deficits (5 items) rated on a 7-point scale ranging from strongly disagree to strongly agree	Handke et al. (2021, 2024)
The Team Leadership Questionnaire (TLQ) is an integrative measurement tool assessing 15 team leader function categories divided into 2 primary phases: 1. Transition: compose team, define mission, establish expectations and goals, structure and plan, train and develop team, sensemaking, provide feedback 2. Action: monitor team, manage team boundaries, challenge team, perform team task, solve problems, provide resources, encourage team self-management, support social climate	Morgeson et al. (2010)
7-item scale rated on a 5-point scale (1=not at all, 5=a great deal)	Mohammed & Nadkarni (2011)

continued

TABLE D-1 Continued

Construct/Scale Name	Construct Definition/Scale Description
What Are the Affective and Performance Outcomes of Team Interactions?	
How happy are team members with how they worked together?	
Team viability	Willingness for team members to continue working together in the future
Individual-level team satisfaction	Overall contentment and positive feelings team members have about their experiences in a team, including relationships with colleagues and task fulfillment
Collaboration	Team members working together to achieve common goals by sharing knowledge and communicating clearly to integrate different perspectives and ideas
How productive is your team?	
Team performance	The extent to which a team collectively achieves its goals and objectives
Comprehensive assessment of team member effectiveness	5 broad areas of team effectiveness: 1. Contributing to the team's work 2. Interacting with teammates 3. Keeping the team on track 4. Expecting quality 5. Having relevant knowledge, skills, and abilities

Measurement Specifics	Scale Development/ Validation Evidence
4-item scale rated on a 7-point Likert-type scale (1=strongly disagree, 7=strongly agree)	Tekleab et al. (2009)
5-item scale rated on a 7-point Likert-type scale (1=very dissatisfied, 7=very satisfied)	Tekleab et al. (2009)
18-item scale measuring satisfaction with collaboration (8 items: acceptance of ideas, communication, researchers' strengths, organization, resolution of conflict, working styles, outside involvement, and discipline involvement), collaboration impact (6 items: meeting productivity, products productivity, overall productivity, research productivity, quality of research, and time burden), and trust and respect (4 items: being comfortable in showing limits, trusting colleagues, being open to criticism, and respect) in research teams. Satisfaction with collaboration and 3 of the collaboration impact items are rated on a 5-point scale ranging from inadequate to excellent. 3 collaboration impact items and trust and respect items are rated on a 5-point Likert-type scale ranging from strongly disagree to strongly agree	Mâsse et al. (2008)
5-item scale (team learning behavior, context support, team leader coaching, team psychological safety, team efficacy) rated on a 5-point Likert scale (1=never, 5=always)	Edmondson (1999)
33-item short scale designed for self- and peer-evaluations of team members in 5 areas: contributing to the team's work, interacting with teammates, keeping the team on track, expecting quality, and having relevant knowledge, skills, and abilities rated on a 5-point Likert-type scale (1=strongly disagree, 5=strongly agree)	Ohland et al. (2012)
87-item full scale designed for self-and peer-evaluations in the 5 areas listed above rated on a Behaviorally Anchored Rating Scale in which raters read through behavioral examples describing a 1, 3, and 5 rating and select the option that best matches ratees' behavior	

continued

TABLE D-1 Continued

Construct/Scale Name	Construct Definition/Scale Description
What Is the Overall State of Readiness, Functioning, Climate, and Outcomes in Your Team?	
TeamSTEPPS Teamwork Perceptions Questionnaire (T-TPQ)	A tool developed by the Agency for Healthcare Research and Quality that helps to identify the strengths and areas for improvement in team dynamics in health care settings
Team Diagnostic Survey (TDS)	An extensive instrument based on a conceptual model of the five enabling conditions that increase the likelihood that a team will perform effectively. It also assesses individual affective reactions

Note: The items to many of the scales provided in Appendix D are freely available at https://ctsi.psu.edu/research-support/team-science-toolbox/assessment/

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Measurement Specifics	Scale Development/ Validation Evidence
35-item instrument assessing 5 dimensions (7 items each) of team functioning in a health care context: team structure, team leadership, situation monitoring, mutual support, and communication. Items are rated on a 5-point Likert scale ranging from strongly agree to strongly disagree	Agency for Healthcare Research and Quality (n.d., 2023)
The TDS measures 5 enabling conditions underlying team success, including whether the task requires a real team rather than in name only (8 items), whether the team has a compelling direction (10 items), a well-designed enabling team structure (20 items), a supportive organizational context (11 items), and available expert coaching (27 items). The survey also measures process criteria of team effectiveness (9 items), the quality of team interpersonal processes (7 items), and individual learning and well-being (10 items). Most items are rated on a 5-point scale ranging from highly inaccurate to highly accurate	Wageman et al. (2005)

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Appendix E

Glossary

accessibility	Highlights the importance of making environments, products, and services usable by people with disabilities. This ensures that all individuals, regardless of their abilities, can participate fully in society.
best practice	An activity or strategy that can enable a science team to collaborate effectively to achieve its goals.
competencies	The knowledge, skills, and abilities required for team success.
context-driven competencies	Competencies required for a specific team working on a specific scientific task.
cross-disciplinary	Collaboration among multiple disciplines toward a shared objective.
faultlines	Ways in which teams may split into sub-groups based on one or more attributes.
group escalation	The tendency of teams to commit poor decisions resulting from pressures for conformity.

hyperauthorship Refers to when scientific papers have hundreds to thousands of authors.

interdisciplinary Blending or juxtaposing concepts and methods from various disciplines.

multidisciplinary Each discipline makes separate contributions in an additive way.

multiteam systems Interdependent sets of two or more component teams pursuing shared superordinate goals.

project management The systematic and deliberate application of knowledge, tools, and expertise to ensure the successful completion of complex projects in a timely and efficient manner.

psychological safety The belief that a group is safe to engage in interpersonal risk.

researcher Any member of a science team conducting and disseminating scientific research.

task-contingent competencies Competencies specific to a type of task but can be applied across different teams.

taskwork The activities associated with achieving a team's goals.

team charter A document written by team members at the beginning of a team's life cycle that defines acceptable team behaviors.

team-contingent competencies Competencies specific to a particular team that can be applied generically across scientific tasks.

team orientation Demonstrating collaborative attitudes and behaviors, rather than those that are more individualistic.

team science Collaborative, interdependent research conducted by more than one individual.

team task analysis	A process to identify work behaviors and associated knowledge, skills, and abilities for successful job or task performance.
teamwork	The interactions among team members that are essential for effective collaboration.
transdisciplinary	Advancement and integration of discipline-specific theories, concepts, and methods.
transdisciplinary orientation	A characteristic that reflects the values, attitudes, beliefs, and behaviors for effective cross-disciplinary collaboration.
transportable competencies	Competencies that have the ability to be applied across a range of tasks and teams.
workshops	Organized, structured interventions designed to bring together individuals to engage in collaborative learning, skill development, and reflection over a few hours to a few days.