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Innovation in the Knowledge Age: implications for collaborative science

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Abstract Current trends validate the notion that multifaceted, multimodal interdisciplinary collaborations lead to increased research productivity in publications and citations, compared to those achieved by individual researchers. Moreover, it may be that scientific breakthroughs are increasingly achieved by interdisciplinary research teams. Nonetheless, despite the perceived importance of collaboration and its bibliometric benefits, today's scientists are still trained to be autonomous, work individually, and encourage their graduate students to do the same—perpetuating values which impede the creation of collaborative space between disciplines. As a consequence, scientists working in teams typically report serious obstacles to collaboration. This paper builds off of recent recommendations from a 2015 National Academies report on the state of team science which emphasizes greater definition of roles, responsibility, accountability, goals, and milestones. However, these recommendations do not address the subjective, relational components of collaboration which can drive innovation and creativity. The relational side of collaboration is key to understanding the capacity and capabilities of the knowledge workers, such as scientists and engineers, who comprise interdisciplinary research teams. The authors' recommendations, grounded in organizational communication and knowledge worker literature, include a renewed focus on the process of organizing through communication rather than focusing on organization as an outcome or consequence of teamwork, leading and cultivating team members rather than managing them, and the need to address self-driven, rather than external, motivations to engage in knowledge work.

Keywords Knowledge work · Collaboration · Team science · Emotional leadership · Communicative construction of organizations · Interdisciplinary science

1 Introduction

Addressing and solving complex environmental science problems require collaboration on the part of multiple scientists, researchers, scholars, practitioners, and external stakeholders. Such an interdisciplinary approach to research and problem solving often requires people to work across disciplinary boundaries, be willing to take alternative perspectives, and communicate in terms and languages different than the discipline in which they were trained. The ability of interdisciplinary teams and leaders to adaptively manage challenging resource management problems can determine their success or failure, but confusion still remains around the best, most appropriate way to address environmental management problems characterized by high levels of uncertainty (Gregory et al. 2006).

However, despite the perceived challenges and difficulties of working in interdisciplinary contexts, the combination of diverse forms of expertise around a common problem creates a context ripe with potential for scientific breakthroughs and increased understanding of complex environmental science problems. One example of interdisciplinary collaboration in environmental science is the Global Lake Ecological Observatory Network (GLEON), where an network of researchers from ecology, ecosystem science, computer science, civil engineering, limnology, biogeochemistry, ecosystem modeling, and microbial

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ecology leverages their combined expertise to understand how biological and physical processes control dissolved oxygen variability in lakes (Langman et al. 2010), create a software tool to process high-frequency physical lake data (Read et al. 2011), examine the effect of weather-related episodic events on global water quality (Jennings et al. 2012), and attempt to use ecosystem modeling to predict high-frequency harmful algal blooms (Kara et al. 2012). GLEON is just one example of a growing trend toward interdisciplinary collaboration which continues to become more important to understanding and ameliorating multi-faceted problems comprised of social, ecological, and technical components.

Research organizations, funding agencies, and some academic institutions are enthusiastic about collaborative approaches and encourage their faculty and staff to work in a more integrative fashion in recognition that teams are likely to have a faster and fuller impact than an individual can achieve working independently (Bennet and Gadlin 2012). Cross-disciplinary teams have become the norm for the conduct and exploration of research in a wide variety of contexts and disciplines (Shen 2008; Stokols 2014), including environmental management, sustainable development, and environmental engineering. Such collaborative initiatives include investigations among researchers and diverse social actors to meet the supposed need of the "knowledge economy" for knowledge contributing to economic growth and social and technological innovation, from both business and nonprofit perspectives (Phillips 2009). However, though research organizations and academic institutions value interdisciplinary endeavors toward creativity and innovation, the ways in which scientists manage and lead this research often continue to be guided by notions grounded in Industrial Age values. The over-emphasis of efficiency, productivity, and control in scientific collaborations can hinder the creative process and fail to both recognize and support human capital, which is foundational to the current Knowledge Age.

Environmental scientists and engineers who engage in collaborative research are knowledge workers (Mladkova 2012). That is, they do not merely work *with* information, but analyze and synthesize information to *create* new ways of understanding complex issues, topics and problems, and implement their findings within their organizations (Frick 2011). In many ways, the evolution of technology, the changing social and physical environments, the resources available to collaborative work, and the changes in the problems that attract scientists' attention have made teamwork attractive, if not necessary, to research (Bennet and Gadlin 2012). The diversity of perspectives and input around a common problem can provide the requisite variety to create and implement solutions to the issue at hand. It is clear that interdisciplinary research is becoming increasingly necessary due to the societal and scientific complexities of problems in the environmental sciences. However, interdisciplinary research projects can be challenging for academic experts who are used to working and researching within their own research silos and who are typically trained in a specific field of theories, methodologies, and research processes (Thompson 2009).

2 Challenges facing interdisciplinary collaborative science

The increased interest in cross-disciplinary, collaborative team science initiatives over the last few decades, coupled with the desire to better understand factors that can either facilitate or constrain the success of these initiatives, has led to the development of an emergent field referred to as the science of team science (SciTS, pronounced "sights") (Falk-Krzesinski et al. 2011; Stokols 2014). Team science refers to the coordinated effort of professionals who focus on a common problem but are trained in different fields. Team science can be conducted within a single, focused discipline, or can span different disciplines. The degree of variation across disciplines, as well as the breadth of levels of analysis, affects the size and complexity of a given team. As such, "the degree of complexity of a given problem that a team tackles can, in turn, influence the breadth and degree of the integration of disciplinary knowledge needed to explain or solve that problem" (Hall et al. 2008a; p. 243). SciTS examines the processes through which teams organize, communicate, and conduct research to find the best, most efficient and predictive way to create and manage scientific teams. SciTS also helps us understand how teams collaborate to achieve scientific breakthroughs in ways that individuals cannot when working in isolation.

In April 2015, the National Academies commissioned the National Research Council to conduct a consensus study of the team science field. The report identified seven key challenges facing interdisciplinary teams.

1. *High diversity of membership* Because science teams demand requisite variety of their roster to solve highly complex problems, their members often come from diverse disciplines and training backgrounds. This leads to the challenge of fostering effective communication and coordination between individuals coming from different, often competing intellectual backgrounds and cultures, both within and outside of academia.
2. *Knowledge integration* The depth of knowledge integration among team members differentiates multi-, inter-, and transdisciplinary teams. The extent to which team members can coordinate across social and

behavioral disciplines with varying values, terminology, work styles, and methodologies affects their ability to be successful.
3. *Team size* Simply put, larger teams face greater challenges of coordinating efforts and communicating.
4. *Goal alignment* Particularly when teams consist of multiple stakeholders within academia, industry, and government, aligning different goals becomes a challenge. Making sure all stakeholders agree and are committed to the same goals is a key challenge for diverse teams, even if members are united under a common problem.
5. *Permeable team and group boundaries* The membership of a team or group might change depending on the phase of the project or the timing of certain expertise as it is required. The shifting nature of who is working on what and when can make it difficult to form connections with team members.
6. *Geographic dispersion* It is highly unlikely that the combination of group members with the exact required expertise and skill sets will be colocated and available to allocate time and resources to a given project in the same funding period.
7. *High task interdependence* Reaching agreement among team members in regard to research approaches and data assessment, as well as the handing off of data and work requirements once a phase of the project is completed, are both fraught with potential for disagreement and conflict.

By conducting a survey of collaborative science and identifying the seven challenges above, the National Academies report served as a step toward synthesis and organization of current team science research and gave scholars and practitioners a foundation upon which to build their capacity to learn and understand how team science unfolds and what we can do to support scientific collaboration. However, there is still much we can learn about and contribute to collaborative science by drawing upon literatures not reflected in the report.

3 Enhancing leadership and assessment of collaborative science

In this paper, we explore the National Academies report's recommendations in regard to determining team effectiveness, leading science teams, and motivating and supporting team members. These three challenges are in the first column of Table 1. We suggest an additional recommendation for each challenge, grounded in literature and findings from organizational communication and knowledge workers.

To be clear, we are not arguing against the validity or legitimacy of the three recommendations from the report, nor do we attempt to disprove their importance in regard to interdisciplinary collaboration. Rather, we seek to expand upon and enhance the report's recommendations for determining team effectiveness, leading science teams, and motivating and supporting team members by furthering our understanding of the relational components of interdisciplinary collaboration. In the following section, we provide additional context for the three National Academies recommendations, each followed in turn by our proposed enhancement.

4 Team effectiveness

4.1 Determining team effectiveness through pre- and post- assessment

The National Academies report suggests two primary measures for determining team effectiveness: pre-project measures such as collaboration plans to be administered either before a project begins or at its outset (Hall et al. 2008b) and post-project measures such as bibliometric analysis, which by its nature provides an outcome assessment of team productivity (Wuchty et al. 2007). Because the goal of collaboration plans is to create a model for communication expectations and standards over the course of the grant (Hall et al. 2008b), the National Academies report recommends their inclusion in future grant applications. As it stands, review criteria for research grants "are typically focused on the technical and scientific merit of the application, and not the potential of the team to collaborate effectively, with few exceptions" (NAS 2015, pp. 9–9). Based on the report, collaboration plans serve to "engage teams and groups in formally considering the various relevant factors that may influence their effectiveness and deliberately and explicitly plan actions that can help maximize their effectiveness of productivity and innovation" (pp. 9–10). Collaboration readiness factors include a researcher's institutional resources, research orientation and leadership qualities, and history of collaboration with on earlier projects (Hall et al. 2008b). In theory, collaboration plans can be highly useful tools which enhance coordination and outline expectations for communication and contributions from team members before a project begins. Assessing the predisposition and orientation of team members toward collaboration and creating standards for collaborative communication between team members are valuable information for a principal investigator to have and disseminate to prospective team members when considering and assembling a team or network for interdisciplinary work.

Table 1 Comparison of NAS recommendations and the authors' recommendations, based on relevant literature

Challenge	NAS report recommendation	Hinrichs et al. recommendation
Determining team effectiveness	*Pre- and post-assessment* Score collaboration readiness before and bibliometric data after team organization occurs	*Real-time assessment* Evaluate the communicative processes of team organizing as they occur
Leading science teams	*Task management* Ensure task-relevant diversity and apply interventions to promote knowledge and skill transfer	*Relational management* Engage in affective management and leadership to promote relational development between members
Motivating and supporting team members	*External loci* Revise university policies for tenure and promotion to reward team-based research	*Internal loci* Create contexts for members to feel autonomy, mastery, and a sense of purpose

In terms of post-project assessment, the primary method of determining a team's effectiveness and output has been evaluating bibliometrics. While bibliometrics often provide a picture of productivity after a project ends, evaluators can also keep track of publications as they occur over the course of a grant project. The number of publications and the degree to which those publications have been cited by the scientific community remain the primary measurement by which interdisciplinary teams' success is judged (Hall et al. 2012; NAS 2015; Wuchty et al. 2007). While bibliometrics are important to assess the relative reach, attractiveness, importance, and applicability of a given study to the broader research community, assessments such as these follow a mindset of organization as the by-product of teamwork, not as a process of teamwork. In addition, because it may take years for a grant project to achieve or find significant results, there is often a delay period of 5 years or more before interdisciplinary network publications surpass those achieved by single investigator grants (Hall et al. 2012). Thus, the National Academies report provides a recommendation for trying to predetermine team effectiveness before a project begins by assessing collaboration readiness factors, as well as measures for effectiveness after, and often during, a project's life span through bibliometrics.

What we don't see, and what current team science research does not fully explain, is how the collaborative process unfolds in interdisciplinary science networks and how that process contributes to the achievement of the network goals. There are many questions which remain unanswered by evaluation measures which take place before and after a project, or which take cross-sectional approaches to data collection once a year over the course of a grant. Within the network, who collaborated with whom? Why? How did team members communicate their individual and subgroup values, goals, and needs to the group? How were goals and priorities established, negotiated, and transformed over the course of the grant project? How did personal and professional relationships between members evolve over those 4 years and beyond? How do successful interdisciplinary teams develop such bibliometric records? What collaborative processes transpired before manuscripts were accepted? How can scientists and scholars engaged in team science research and practice emulate, model, and reproduce communication and coordination processes of successful teams if we do not examine these strategies as they occur? It is true that collaboration readiness plans can help identify potential areas of conflict or collaboration for a network, but peoples' positions and commitments may change over the course of a multi-year grant. In addition, by focusing on bibliometric outcomes rather than the processes through which results and publications come to be, we miss out not only on an important understanding of how and why things occur as they do, but also the opportunity to identify and troubleshoot problematic developments if and when they occur.

4.2 A renewed focus on organizing processes of effective interdisciplinary teamwork

Where the report focuses on pre- and post-assessments of team effectiveness and success, our recommendation is to broaden these assessments to include a focus on the communicative processes of organizing, and examine the ways in which team members' communication creates and changes structures which guide future team interactions. If we can gain a better understanding of what collaboration looks and sounds like in practice, we can learn how to best troubleshoot and address conflict that arises, as well as create contexts for conflict to be a productive and potentially rewarding experience for team members. We need to better understand how to create, lead, and realize the potential of interdisciplinary scientific teams comprised of knowledge workers. Scholars who study organizational communication focus on the outcomes or consequences of team organization, as well as the organizing processes of researchers, practitioners, and stakeholders in team science settings. A focus on the real-time interaction and

communication processes of knowledge workers, as well as an examination of which kinds of communication interactions both enable and constrain teamwork practices, can provide a situated understanding of interdisciplinary, collaborative processes which is yet unexplored in both the team science and knowledge worker literature.

Such a focus provides additional understanding of team processes which builds on collaboration readiness plans and bibliometrics. It is not enough to graph a number of publications, count funded grant awards, or elicit survey self-reports of intention to collaborate before a project begins. We must add to these pre- and post-project assessments by deepening our understanding of what happens as teams interact, communicate, and work to fulfill the objectives outlined in their grant application. By examining the communicative process of organizing in these settings and acknowledging interdisciplinary teams as discursive constructions (Fairhurst and Putnam 2004), organizational communication scholars can apply the communicative constitution of organizations (CCO) framework (Bisel 2009; McPhee and Zaug 2000) to understanding interdisciplinary research teams. This framework asks questions such as: How do team communicative processes constitute, or give form to, team organizing? What are the communicative processes that lead to this kind of organizing? How do these communicative processes replicate themselves and shape future interactions?

The CCO framework is closely tied to Giddens' (1984) development of structuration theory. A sociologist by training, Giddens posits a paradox in social life between the duality of structure and agency, wherein the enactments of agency become structures which, over time, both (re)produce and inhibit possibilities for future agency enactment (Bisel 2009). Examining interdisciplinary networks and teams through a CCO lens positions networks and teams as being brought into being both by and through communication, for it is through network members' interactions that they orient themselves toward one another, create meaning, and establish the foundation for structures which will become the overarching network (Schoeneborn et al. 2014). This means that all interactions within interdisciplinary collaboration are inherently meaning-laden and communicative, whether that interaction is a quick email, an annual meeting, a friendly get-together at a conference, a text message or phone call, a formal research presentation, or a site visit. CCO scholars have used the framework to investigate how organizational members' continued (re)negotiation of organizational identity in everyday interactions contributes to the production of the organization itself (Chaput et al. 2011), explore how organizations can form sociomaterially and are authored into being through members' text and information technology platforms (Güney and Cresswell 2012), conceptualize corporate social responsibility as a voice which conceptualizes ethics and responsibility within an entire organization, rather than just an instrument or tool for achieving organizational goals (Schoeneborn and Trittin 2013), and the construction and maintenance of organizational identity through social media communication (Thurlow and Yue 2014).

By understanding how leadership, motivation, and teamwork processes occur in situated interaction, as well as the communicative structures which enable and constrain processes which can either enrich or detract from personal and professional development of team members, we can identify problematic areas of science collaboration and support those which can lead to scientific breakthroughs. Organizational communication and team science scholars are only beginning to scratch the surface of understanding the organizing processes of knowledge and ways of knowing (Iverson and McPhee 2002, 2008; Kuhn 2002; Kuhn and Jackson 2008; Treem 2012) which may be applied to workers in knowledge-creation settings. Because understanding the process of knowledge creation and sharing is fundamental to enhancing interdisciplinary team science, taking a CCO approach to better grasp and improve team processes is valuable to both the team science community and organizational communication scholars.

In practice, the real-time assessment of the communicative constitution of organizations requires social scientists (or other professionals) trained in qualitative data collection and analysis to embed themselves in interdisciplinary teams or networks and become participant observers (Tracy 2013). Becoming a participant observer within a given group or network allows the researcher access to micro-level interactions which may go unnoticed in annual reviews, or be unconsciously carried out by team members and therefore unreported through self-report measures like surveys or questionnaires. As participant observers, social scientists can act as both internal and external reviewers with an understanding of the communicative processes of the group as well as knowledge of the broader implications of the continued negotiation between agency and structure in interdisciplinary teamwork processes. By witnessing and experiencing how team members communicatively construct the reality of their interdisciplinary collaboration and negotiate agency and structure through their interactions with other team members, participant observers embedded within the network can also provide a feedback loop to project management based on iterative analysis of their observations and findings, as well as current literature in organizational communication and team science. This continued participant observation and feedback can help project leaders provide strategic and ongoing leadership to network members.

5 Team leadership

5.1 Ensuring task management and role diversity in science leadership

To make conclusions and recommendations about how to best manage and lead interdisciplinary teams, the National Academies report draws heavily upon literatures in business, management, and organizational psychology. The report acknowledges that there is "a large and robust body of social science research on groups and teams in contexts outside of science, such as military teams, industrial research and development teams, production and sales teams, and professional sports teams" (NAS 2015, p. 3) and extrapolates findings from those fields onto interdisciplinary team science. The committee behind the report makes a case for the value of pulling findings and implications from business, management, and organizational psychology due to extant similarities between the teams and groups in other contexts and those engaging in team science.

The report suggests that leaders of science teams and groups consider applying analytic methods such as task analysis, cognitive modeling, and job analysis to help guide team composition and assembly. The desired outcome is a perfect match of participants' knowledge and skills with project needs. In regard to leadership, the report also identifies and suggests three professional development training exercises for leaders to use in their groups, teams, and networks. The first involves cross-training on another team member's task and role responsibilities to teach interpositional knowledge (Gorman et al. 2010). The second, team reflexivity training (Gurtner et al. 2007), asks members to reflect on prior poor performance, ascertain why objectives were or were not met, and determine how to improve performance in the future. The last is knowledge development training (Rentsch et al. 2010), which creates contexts for team members to improve knowledge transfer and cognitive congruence in the interest of higher team performance. All three of these leadership interventions hold the potential to create contexts for knowledge transfer and greater appreciation of the skills and abilities of team members. Task analysis can help leaders understand the strengths and weaknesses of potential team members and ensure the requisite variety and skills sets within their team during the assembly stage. The recommendation to lead science teams by ensuring task-relevant diversity and applying nonscience interventions for professional development is an important one supported by findings from studies on professional development training.

However, the primary focus of these training interventions is the cognitive component of collaboration—that is, the transmission of knowledge, skills, and ideas. What is not evident in the leadership training objectives as discussed in the National Academies report is the affective, relational, interpersonal component of interdisciplinary collaboration. There are growing bodies of literature which point to the importance and effect of emotion and positive affect on creativity and collaborative processes (i.e., Amabile et al. 2005; Andrade and Ariely 2009; Barsade and Gibson 2007; Barsade and O'Neill 2016; Chang et al. 2011; Hareli and Rafaeli 2008; Shin 2014). While it is indeed important to understand the knowledge and skills of team members so that you can leverage each other's strengths to the advantage of the group, it is arguably just as important to understand how to relate to and approach that team member on an interpersonal level. The ability to lead from an affective, as well as cognitive stance in regard to collaboration, is particularly significant if we acknowledge that the people who comprise interdisciplinary, collaborative research teams are knowledge workers and, as such, do not fit into Industrial Age notions of management and control—values which still dominate much of the research and findings used to draw conclusions about collaborative science in the report.

5.2 Leading knowledge assets through relational management

Our second recommendation builds upon the leadership conclusions in the National Academies report and calls attention to the relational management necessary for leaders of interdisciplinary science groups, teams, or networks. After all, knowledge workers defy conventional notions of supervision and control (Carleton 2011) which characterize much of the business, management, and organizational psychology resources used in the report. When managing and/or leading a knowledge worker, it is important to remember that these valuable employees are "associates," not "subordinates" (Drucker 2002). Unlike business employees who may be assigned to a particular client, project, or case, scientists and other kinds of knowledge workers often volunteer to join and contribute to projects which they find appealing and of which they want to be a part. Davenport et al. (2002) conducted a study to find out the best way to maximize performance among knowledge workers and found that the most popular approach to managing this subset of employees was to "hire smart people and leave them alone." Autonomy has been determined to be a key component of managing and leading knowledge workers, as it acknowledges that these people do not need to be micromanaged and are capable of conducting their work without rigid structures or standards set by management. Such an approach has implications for

strict organizational hierarchies and traditional notions of organizational power and control which are still pervasive in team science.

These findings suggest that interdisciplinary networks comprised of knowledge workers would benefit from a more horizontal management structure (Grant 1996) which takes care to cultivate personal relationships between network members as a cohesive whole, not just develop individuals professionally. If we take a knowledge-based approach to understanding research-oriented interdisciplinary teams and networks (Grant 1996), then we consider knowledge to be the team's most competitive advantage. The knowledge-based approach to organizing processes of teams alters notions of organizational power and an organization's decision-making structure. If a team's greatest resource is knowledge, and that knowledge is held by the knowledge workers, then power lies in the hands of the scientists themselves, requiring a more dual control system between team members and leaders. This perspective changes our traditional shareholder notions of organizational control. For this reason, a strict, bureaucratic organizational hierarchy is of limited usefulness in a knowledge-based scientific team. This perspective applies particularly to research teams in which disciplinary representatives are the top in their fields and possess a high degree of specialized knowledge which is not represented elsewhere in the group. Thus, while collaboration plans can create clear expectations and standards for behavior within scientific teams, the method through which a leader creates and implements that plan can impact its success and adoption within a team. Acknowledging the power differences and autonomous nature of knowledge workers requires researchers to re-evaluate our notions of power hierarchies and the nature of work and communication in knowledge-creating organizations.

In practice, relational management of knowledge workers can take many forms. Leaders can create contexts for relationship building to occur alongside creative brainstorming for project goals or as an objective in its own right. These contexts do not have to be formal—monthly phone calls can begin with a personal check-in with other members present, or members colocated in the same city or institution can have semi-regular meetings to increase familiarity and get to know each other outside of the grant project. More formal, extensive retreats in neutral locations can also provide team members the opportunity to develop personal relationships which can then increase trust and creative output (Parker and Hackett 2012). In addition to personal relational management, leaders can support the professional relationships within a network by using a more horizontal management style and inviting network members to be part of the decision-making process. Inviting network members to co-create and establish measures of their own productivity can go a long way toward helping knowledge workers feel appreciated, respected, and acknowledged as members of the team and valuable contributors toward a relationship (Drucker 1999, 2002).

6 Team motivation and support

6.1 Motivating and supporting team members through institutional structures

The National Academies report did not account for any systemic, national data on university policies designed to help promotion and tenure committees recognize and reward team science because no data of the sort exist (NAS 2015). The risks of engaging in interdisciplinary work vary by field, with some disciplines placing greater emphasis on independent, single-authored work early on and only giving way to collaborative work once tenure has already been achieved. Others employ a more collaborative model of learning in undergraduate education. Regardless, the report does assert that "disciplinary norms for assigning credit based on the order of the authors' names may not help in assigning credit for interdisciplinary publications" (pp. 8–6). Scholars who engage in interdisciplinary collaboration find themselves having to provide detailed descriptions and percentage breakdowns of their contributions made to every publication and grant on their record.

The report draws attention to the difference in perceived agency between business employees and scientists, acknowledging that "unlike business employees who are typically assigned to work teams, scientists often voluntarily join science teams or groups. Therefore, scientists tend to have autonomy and operate like 'free agents'" (pp. 1–15). However, the lack of ubiquitous tenure and promotion policies which allow for the freedom and autonomy of pursuing interdisciplinary grants and publications which will then be acknowledged by one's tenure review committee suggests otherwise. It may be that scientists feel more autonomous than business employees, but exercising that autonomy by choosing work in interdisciplinary contexts puts their tenure review success at risk. Nonetheless, right now the report's primary recommendation in regard to motivating and supporting interdisciplinary knowledge workers is that universities and disciplinary associations should develop and evaluate more specific criteria for recognizing and allocating credit for team-based work to help tenure and promotion committees review candidates (pp. 8–16).

The current focus within team science on external loci of motivation (tenure and promotion policies, organizational resources, institutional infrastructure) provides one way of understanding how to motivate and encourage

people engaging in team science, as well as increased understanding for the obstacles which often prevent people from engaging in this kind of work. From the report, it is clear that the academic institutions in the USA do not yet have widely accepted structures in place which allow for the pursuit of interdisciplinary collaboration which directly translates into tenure and promotion criteria. This is a systemic problem which will continue to face scholars and researchers in the years ahead. However, we also need to understand how institutions and leaders can support interdisciplinary collaboration at the interpersonal team level. In addition to ameliorating tenure and promotion obstacles in the interest of supporting collaborative work across disciplines, we also need to understand and acknowledge the subjective, self-driven motivations which inspire knowledge workers to engage in team science and participate in creative, innovative, and productive ways with their team.

6.2 Inspiring and supporting self-driven desires of knowledge workers

The National Academies report includes an entire chapter on institutional and organizational support for team science which outlines the importance of providing clear external motivations and acknowledgements for scientists and others who engage in collaborative knowledge work. While it is undoubtedly true that tenure and promotion policies (in countries which uphold them) represent important factors and, often obstacles, for individuals to engage in particular kinds of scientific work, there is more that we can understand about encouraging collaborative science if we once again turn to research on inspiring and supporting knowledge workers. Our third recommendation is to broaden notions of supporting interdisciplinary collaboration past systemic tenure and promotion policies so that we may recognize and support the subjective, self-driven desire of individuals to feel autonomy, mastery, and a sense of purpose in their everyday lives (Pink 2011).

As much as knowledge workers desire autonomy and the freedom to make their own priorities, it can be challenging for them to be effectively motivated. When knowledge workers are not feeling motivated, what is often required is a change in attitude (Drucker 1999). Frick (2011) conducted a study to find factors associated with highly motivated knowledge workers and found that the top motivating factors were, in no particular order, their belief in the organizational mission, the perception that they were doing a public service, their relationships with their coworkers, and their perception of their work as meaningful. On the other hand, factors associated with negative, or lack of, motivation were a perceived lack of support, dissatisfaction with their superiors, having to work with substandard coworkers, and a lack of resources. This is an important distinction to make in regard to knowledge workers. Carleton (2011) found that salary and monetary incentives are not as effective in motivating knowledge workers as are opportunities to foster learning, engagement, and understanding. Indeed, most knowledge workers see themselves in a symbiotic relationship with their organization or work group, where each helps the other advance and succeed.

The report does not integrate research examining the influence of affective, subjective desires such as mastery, autonomy, or a feeling of achievement and purpose on a team member's likelihood to engage in interdisciplinary science research, despite the fact that the scholars and practitioners comprising these teams are unquestionably knowledge workers. The broad-level assumption seems to be that the best way to incentivize people to work in interdisciplinary settings is to make sure tenure and promotion policies will acknowledge the individual once all is said and done. The assumptions and recommendations evident in the report do reflect certain tangible components of collaborative work and shine a bright light on the embedded structures of tenure and promotion which create obstacles to fully engaging in interdisciplinary collaboration. We want to build on the recommendations made in the report by taking into account the knowledge worker literature which suggests that scientists and engineers might very well be motivated not just by tenure and promotion, but more so by the opportunity to demonstrate their knowledge, master new concepts, create solutions which can positively impact the greater scientific and social community, and provide them a context to collaborate with people whom they respect and have a desire to form relationships.

In practice, inspiring and supporting the self-driven desires of knowledge workers require leaders, deans, and department chairs to create spaces where scholars and researchers can communicate what they need to feel a sense of mastery and purpose. It is true that tenure grants a sense of autonomy to those who achieve it, but there are greater departmental and institutional factors which can still impede the personal and professional development of faculty and scholars even after they have achieved tenure. Creating contexts for open, vulnerable communication of knowledge worker wishes and needs necessitates a departmental or network culture of psychological safety, a term coined by Amy Edmondson to reflect a team's shared belief that members are respected and accepted, and can take interpersonal risks (Edmondson 1999; Edmondson et al. 2004; Nembhard and Edmondson 2006). However, once a member's needs or desires are communicated, a leader needs to be willing to help identify opportunities and potential outlets for that creative energy, as well as assist in

removing obstacles which might deter an individual or team from pursuing a project of importance.

Thus, administration leaders, department chairs, and deans need to develop and/or create contexts for more transparent communication about the tensions between the subjective nature of evaluating an individual's contribution to interdisciplinary collaboration and the objective, numerical measures of counting grant dollars accrued and published papers as evidence of acceptable scholarly work. This tension pervades tenure-granting institutions and might prevent a faculty member or researcher from working in interdisciplinary contexts until he or she achieves job security—an achievement which may take years to realize, if it is realized at all. What administrative officials and leaders can do is open up pathways for metacommunication (Tracy 2004) about these tensions to bring them into the open and begin working toward solutions. Such an approach can help a knowledge worker feel valued and respected within a team, network, or department, even if his or her institution's tenure and promotion policies remain obstacles.

7 Implications for future research on interdisciplinary collaboration

In sum, the National Academies report provides important insights as to the nature of interdisciplinary work and synthesizes much of the existing team science research, opening the door for future research on collaborative science. By focusing primarily on findings from business, management, and psychology, the current team science research agenda provides a foundation upon which to build and continue exploring areas of literature which can enhance our understanding of the best practices for leading, enhancing, and cultivating productive contexts for scientific breakthroughs—most notably through organizational communication frameworks and findings from prior knowledge worker research.

7.1 Future directions for real-time assessment of team effectiveness

Future directions for research examining real-time assessment of team effectiveness should seek to answer such questions as: How do team communicative processes constitute, or give form to, team organizing? What are the communicative processes that lead to this kind of organizing? How do these communicative processes replicate themselves and shape future interactions? How can leaders and managers adapt and integrate the changing needs of their team throughout the lifespan of the project? In addition, future assessments of interdisciplinary collaboration and team science should integrate all three evaluation measures, combining the explanatory powers of pre-, post-, and ongoing processual measures of team effectiveness. Another valuable contribution to evaluating team assessment would be a measure which enhances bibliometric analysis. That is, can we begin to make predictions about a team or network's eventual publication record as a result of key markers of communication or behavior during the project itself? If so, how can we perpetuate positive interpersonal and group communication in future collaborations?

However, it is worth noting that access to grant-funded projects and other kinds of interdisciplinary research networks is often difficult for social scientists and organizational communication researchers, many of whom are brought into a grant project once it is fully underway and members have already established and codified expectations and norms for behavior, or who are not part of the grant team at all and must try to make retroactive sense of members' communication and behavior. While grant applications and other funded projects often require a plan for evaluation as part of the application process, many continue to use cross-sectional measures rather than embedding a social scientist as part of the network itself. Future directions within the realm of project assessment and evaluation might compare the progress and productivity of teams and networks which use annual or semi-annual self-report surveys to others which perform ongoing evaluation and assessment through an embedded participant observer.

7.2 Future directions for relational management of knowledge workers

Future research examining the relational management of knowledge workers in interdisciplinary science should compare and contrast the impact of relational interventions when compared to those organized around knowledge transfer and skill acquisition. Based on our review here, relational management of team members can directly influence the success with which knowledge and skills are grasped by others in the network, as well as the decision-making processes of the whole group. Research clearly demonstrates the influence of emotion and relational components of teamwork on trust and decision-making processes (Andrade and Ariely 2009; Ayoko et al. 2008; Barsade and Gibson 2012; Catino and Patriotta 2013; Kelly and Barsade 2001), and yet few studies have examined situated, interactional data which reveals how these relational components unfold between team members in real time (exceptions include Kangasharju and Nikko 2009; Thompson 2009). If both affective and cognitive components of collaboration are equally valuable, future research

should address how we can create training and development programs for interdisciplinary collaborators which not only enhance knowledge and skill development and transfer, while also creating contexts for relationship building and interpersonal relating.

Another area of future research in regard to relational management of knowledge workers is creating a better understanding of the shifting nature of power and control in knowledge-creation spaces. Research questions in this area should explore the difference between horizontal and vertical management in interdisciplinary networks and groups, as well as examine correlations between management structure, hierarchy, satisfaction, productivity, and bibliometric outputs of networks subscribing to different management and leadership styles. These studies can combine pre-project collaboration readiness factors with real-time assessment and observation of leadership communication, as well as post-project bibliometric measures. However, because we know that interdisciplinary networks often have a lag time of approximately 5 years before bibliometrics surpass those of investigator-initiated grants (Hall et al. 2012), researchers pursuing this line of research should expect a multi-year study which can yield valuable insights into the relational components of working in interdisciplinary contexts.

7.3 Future directions for inspiring and supporting knowledge workers

The overarching tenure and promotion policies which govern much of the United States' academic institutions seek to create objective measures as evidence of individual scholarly work, as opposed to the more subjective nature of evaluating an individual's contribution to an interdisciplinary collaboration. Future areas of research which seek to understand and support knowledge workers, particularly in academic settings, should continue exploring this tension and dig deeper into socially constructed expectations of scholarship and collaboration. This can include a broader level discourse analysis which asks questions such as: What is the relationship between micro-, meso-, and macro-levels of discourse in regard to interdisciplinary collaboration and institutional advancement? Who institutes these discourses? Who holds power in these discourses? How have the discourses around tenure and collaboration in academia changed over time, if at all? How do discourses of tenure and promotion in the USA compare to discourses of career advancement in countries where tenure does not exist? By better understanding the current discourses and conversations regarding professional advancement, scholars in organizational communication and team science can better begin changing and/or introducing new discourses which are more inclusive of interdisciplinary, collaborative work.

In addition to understanding larger societal discourses around tenure and promotion as they pertain to interdisciplinary collaboration, future research should examine the ways in which administrators, leaders, and team members themselves can begin to remove obstacles to working in new, risky, and uncertain contexts. How do these obstacles manifest? How are these obstacles framed by institutions, administrators, and individual researchers? How can we begin to create contexts which either ameliorate the obstacle or work around it?

In this paper, we have proposed three recommendations which we believe enhance findings in the 2015 National Academies report, *enhancing the effectiveness of team science*. Our recommendations are grounded in organizational communication and knowledge worker literature, which we believe can help team science scholars and practitioners better understand the relational components of working across disciplinary boundaries, as well as provide new theoretical frameworks which conceive of interdisciplinary networks as continuously changing, growing, and evolving through members' communicative construction of reality. There are numerous directions for future research proposed here which create new opportunities for further understanding and improvement of interdisciplinary collaboration.

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