Enhancing the Effectiveness of Team Science

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Overview of the Research on Team Effectiveness

This chapter summarizes the research literature on team effectiveness, highlighting findings on the key features that create challenges for team science outlined in Chapter 1. Based on its review of the literature (e.g., Kozlowski and Ilgen, 2006; Marks, Mathieu, and Zaccaro, 2001; Salas, Goodwin, and Burke, 2009), the committee defines team effectiveness as follows:

> Team effectiveness, also referred to as team performance, is a team's capacity to achieve its goals and objectives. This capacity to achieve goals and objectives leads to improved outcomes for the team members (e.g., team member satisfaction and willingness to remain together) as well as outcomes produced or influenced by the team. In a science team or larger group, the outcomes include new research findings or methods and may also include translational applications of the research.

More than half a century of research on team effectiveness (Kozlowski and Ilgen, 2006) provides a foundation for identifying team process factors that contribute to team effectiveness, as well as actions and interventions that can be used to shape the quality of those processes. As noted in Chapter 1, this evidence base is comprised primarily of studies focusing on teams in contexts outside of science, such as the military, business, and health care. These teams share many of the seven features that can create challenges for team science introduced in Chapter 1. For example, in corporations, top management teams and project teams are often composed of members from diverse corporate functions, and these teams seek to deeply integrate their diverse expertise in order to achieve business goals. Therefore, the committee believes the evidence on teams in other contexts can be translated and applied to improve the effectiveness of science teams and larger groups.

This chapter begins by presenting critical background information—highlighting key considerations for understanding team effectiveness and presenting theoretical models that conceptualize team processes as the primary mechanisms for promoting team effectiveness. The chapter then highlights those team process factors shown to influence team effectiveness (Ilgen et al., 2005; Kozlowski and Bell, 2003, 2013; Kozlowski and Ilgen, 2006; Mathieu et al., 2008), based on well-established research (i.e., meta-analytic findings [see Box 3-1] or systematic streams of empirical research). Next, the discussion turns to interventions that can be used to improve team processes and thereby contribute to team effectiveness; these are discussed in greater detail in subsequent chapters. This is followed by a discussion of how this foundational knowledge can inform team science, a description of models of science team and effectiveness, and a discussion of areas in which further research is needed to address the challenges emerging from the seven features outlined in Chapter 1.

BOX 3-1
What Is a Meta-Analysis?

The foundation of scientific research is based on primary studies that collect data under a given set of conditions (i.e., experiments or field studies) and examine effects on, or relationships among, the observed variables of interest. However, all research is subject to limitations and no single study is definitive. Thus, there is considerable value in the use of a meta-analysis to quantitatively combine multiple primary studies and summarize their findings. The basic steps of a meta-analysis include: (a) conducting a thorough search for relevant studies (including unpublished ones); (b) converting test statistics to effect sizes (i.e., an index capturing the strength of the relationship between two variables); (c) weighing the effect size from a study by its sample size (i.e., studies with larger samples presumably contain less-biased estimates of the true effect size and therefore receive higher weight); and (d) combining the effect sizes across studies to estimate the overall strength and meaningfulness of a given relationship (i.e., testing for statistical significance and establishing confidence intervals). Depending on the number, scope, and sample size of the primary studies, the average effect size can be generalized as a population estimate of the relationship in question. In addition, a meta-analysis often corrects the raw averaged effect size for a variety of statistical artifacts (i.e., measurement unreliability, restriction of range from sampling) to improve population effect size estimate.

Depending on what it is possible to code from the primary studies, a meta-analysis may examine other factors that moderate or change the strength of a relationship (e.g., whether the research was experimental or field based; whether it was one type of team vs. another type of team).

Effect sizes can be reported using a variety of indices, but *r* (i.e., correlation) is often used for uncorrected effects and ρ (i.e., rho) for corrected ones. The interpretation of *r* and ρ is straightforward. The indices range from -1.00 to +1.00 to indicate the strength and direction of the relationship. Cohen's (1992) Rules-of-Thumb designate correlations (*r)* of .10 as small, .25 as medium, and .40 as large effect sizes. Squaring the two indicators gives a direct measure of the proportion of variance shared by both variables. Thus, an effect size of .35 accounts for about 12 percent of shared variance. Although that may appear to be a small amount of explained variance, one also has to consider practical significance. Being able to better predict that 12 percent of patients would respond favorably to a drug or improving science team innovation by 12 percent based on a leadership or teamwork intervention may be very practically meaningful. Thus, a meta-analysis provides a rigorous quantitative summary of a body of empirical research.

SOURCE: Created by the committee.

End of Box 3-1

BACKGROUND: KEY CONSIDERATIONS AND THEORETICAL MODELS AND FRAMEWORKS

Key Considerations

One key consideration regarding team effectiveness is that it is inherently multilevel, composed of individual, team, and higher-level influences that unfold over time (Kozlowski and Klein, 2000). This means that, at a minimum, three levels of the system need to be conceptually embraced to understand team effectiveness (i.e., within person over time, individuals within team, and between team or contextual effects; Kozlowski, 2012). Broader systems that encompass the organization, multiple teams, or networks are obviously even more complex. Moreover, individual scientists may be part of multiple research projects spread across many unique teams and thus are "partially included" in their teams (Allport, 1932). As noted in Chapter 1, a recent study suggests that scientists' level of participation (i.e., inclusion) in a team is related to team performance, with higher participation related to increased success (Cummings and Haas, 2012).

A second critical consideration for understanding, managing, and improving team effectiveness is the degree of complexity of the workflow structure of the team task (Steiner, 1972). In simple structures, team members' individual contributions are pooled together or constructed in a fixed serial sequence (e.g., in a multidisciplinary team, members trained in different disciplines combine their expertise in an additive way). Complex structures incorporate the integration of knowledge and tasks through collaboration and feedback links, making the quality of team member interaction more important to team effectiveness.

A final key consideration is the dynamic interactions and evolution of the team over time. According to Kozlowski and Klein (2000, p. 55):

> "A phenomenon is emergent when it originates in the cognition, affect, behaviors, or other characteristics of individuals, is amplified by their interactions, and manifests as a higher-level, collective phenomenon."

In other words, emergent phenomena arise from interactions and exchange among individuals over time to yield team-level characteristics. Emergent phenomena unfold over time as part of the team development process. Time is also pertinent with respect to how teams themselves evolve. For example, Cash et al. (2003) reported on the evolution of a transdisciplinary group focused on developing improved varieties of wheat and corn. The authors reported that a strictly sequential approach—in which scientists first developed new crops in the laboratory or field and then later handed them over to native farmers—did not lead to widespread use of the new crops. However, when the native farmers were brought into the research at an earlier point in time, as valued participants and partners with the scientists, the group produced new crops that were widely used. Relatedly, teams have different time frames for interaction (i.e., their lifecycle or longevity), and this too will alter the emergent dynamics (e.g., Kozlowski et al., 1999; Kozlowski and Klein, 2000; Marks. Mathieu, and Zaccaro, 2001).

Theoretical Models and Frameworks

Most of the research on team effectiveness has been substantially influenced by the input-process-output (IPO) heuristic posed by McGrath (1964). Inputs comprise (a) the collection of individual differences across team members that determine team composition; (b) team design characteristics (e.g., information, resources); and (c) the nature of the problem that is the focus of the team's work activity. Processes comprise the means by which team members' cognition, motivation, affect, and behavior enable (or inhibit) members to combine their resources to meet task demands.

Although team processes are conceptually dynamic, researchers generally assess them at a single point in time. Hence, they are often represented in the research literature by static perceptions or emergent states (Marks, Mathieu, and Zaccaro, 2001). More recently, team processes have been represented by dynamic or sequential patterns of communications (Gorman, Amazeen, and Cooke, 2010) or actions (Kozlowski, in press). In this report, the committee uses the term "team processes" to refer to both dynamic team processes (e.g., communication patterns) and the emergent perceptual states that result from these processes (e.g., cohesion).

Contemporary theories of team effectiveness build on the IPO heuristic, but are more explicit regarding its inherent dynamics. For example, Kozlowski et al. (1996, 1999) and Marks, Mathieu, and Zaccaro (2001) emphasized the cyclical and episodic nature of the IPO linkages.

Similarly, Ilgen et al. (2005) and Mathieu et al. (2008) are explicit about the feedback loop linking team outputs and subsequent inputs. Accordingly, various authors have urged more attention to team dynamics in research (e.g., Cronin, Weingart, and Todorova, 2011; Cooke et al., 2013) and advances in research design (Kozlowski, in press; Kozlowski et al., 2013) to better capture these dynamics and more clearly specify the relationships between variables. Moving from broad heuristics to more well-defined theoretical models would benefit the field.

In their monograph, Kozlowski and Ilgen (2006) adopted the dynamic IPO conceptualization and focused on those team processes with well-established, empirically supported contributions to team effectiveness. They then considered actions and interventions in three aspects of a team—composition, training, and leadership—that shape team processes and thus can be used to enhance team effectiveness (as shown in the shaded areas of Figure 3-1). Given the preponderance of literature that follows the IPO conceptualization, we emulate that approach in this chapter.

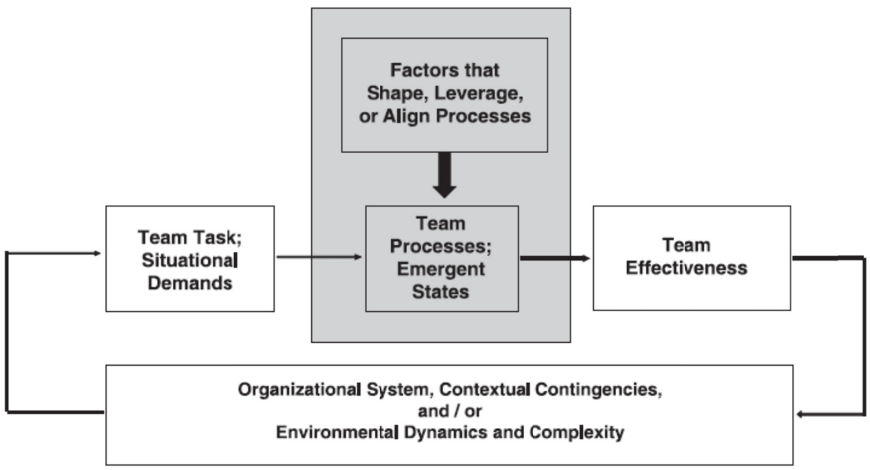

FIGURE 3-1 Theoretical framework and review focus.
SOURCE: Reproduced from Kozlowski and Ilgen (2006). Reprinted with permission.

TEAM PROCESSES: THE UNDERPINNINGS OF TEAM EFFECTIVENESS

Team processes are the means by which team members marshal and coordinate their individual resources—cognitive, affective, and behavioral—to meet task demands necessary for collective goal accomplishment. When a team's cognitive, motivational, and behavioral resources are appropriately aligned with task demands, the team is effective. Thus, team processes are the primary leverage point for enhancing team effectiveness. The committee's review in this section examines team cognitive, motivational and affective, and behavioral processes, discussed below.

Cognitive Team Processes

Teams have been characterized as information processing systems (Hinsz, Tindale, and Vollrath, 1997) such that their collective cognition drives task-relevant interactions. Here we discuss several cognitive and perceptual processes that are related to team effectiveness: team mental models and transactive memory, cognitive team interaction, team climate, and psychological safety.

Team Mental Models and Transactive Memory

Team mental models are conceptualized as shared understandings about "task requirements, procedures, and role responsibilities" that guide team performance (Cannon-Bowers, Salas, and Converse, 1993, p. 222). Whereas team mental models represent common understandings, transactive memory captures the distribution of unique knowledge across team members (Wegner, Giuliano, and Hertel, 1985), especially their shared understanding of "who knows what" such that they can access and direct relevant knowledge (Austin, 2003; Lewis, 2003, 2004; Lewis et al., 2007; Lewis, Lange, and Gillis, 2005; Liang, Moreland, and Argote, 1995). Meta-analytic findings indicate that both processes are positively related to team processes ($\rho = .43$) and team performance (i.e., effectiveness) ($\rho = .38$) (DeChurch and Mesmer-Magnus, 2010).

Studies of science teams and larger groups have also found that shared mental models enhance team effectiveness. To cite just a few examples, a study of research and development teams in India (Misra, 2011) found that shared mental models were positively related to team creativity. A study focusing on larger groups of European scientists participating in interdisciplinary and transdisciplinary environmental research found that those groups whose members developed a shared understanding of the research goals were much more likely to succeed in synthesizing their perspectives to achieve those goals than those who did not develop shared understandings (Defila, DiGiulio, and Scheuermann, 2006). In a recent qualitative study of the National Cancer Institute's Transdisciplinary Research on Energetics and Cancer Center, investigators and trainees reported that articulating concrete shared goals (through grant applications, for example) and investing time and effort in developing mutual understanding were essential to successfully carrying out their research projects (Vogel et al., 2014).

Both team mental models and transactive memory have the potential to be shaped in ways that enhance team effectiveness. For example, a number of studies demonstrate that mental models can be influenced by training, leadership, shared or common experiences, and contextual conditions (Cannon-Bowers, 2007; see also Kozlowski and Bell, 2003, 2013; Kozlowski and Ilgen, 2006; Mathieu et al., 2008; Mohammed, Ferzandi, and Hamilton, 2010 for reviews). Similarly, transactive memory systems are formed through shared experiences in working together and training (see Bell et al., 2012; Blickensderfer, Cannon-Bowers, and Salas, 1997; Kozlowski and Bell, 2003, 2012; Kozlowski and Ilgen, 2006; Mathieu et al., 2008; Mohammed, Ferzandi, and Hamilton, 2010, for reviews). Accordingly, it is often recommended that training be designed to foster development of appropriate team mental models and transactive memory systems and that leaders shape early team developmental experiences to build shared mental models and transactive memory (Kozlowski and Ilgen, 2006).

Theories of Team Cognition

Team mental models and transactive memory focus on cognitive structure or knowledge and how that knowledge is shared or distributed among team members. Although knowledge certainly contributes to team cognition, it is not equivalent to team-level cognitive processing. Teams often actively engage in cognitive processes such as decision-making, problem-solving, situation assessment, planning, and knowledge-sharing (Brannick et al., 1995; Letsky et al., 2008). The interdependence of team members necessitates cognitive interaction or coordination, often manifested through communication, the essential building block of team cognition (Cooke et al., 2013). These interactions facilitate information and knowledge sharing processes that are foundational to decision-making, problem-solving, and the other collaborative cognitive processes mentioned above (Fiore et al., 2010a).

The theory of interactive team cognition proposes that team interaction, often in the form of explicit communication, is at the heart of team cognition and in many cases accounts more than knowledge inputs for variance in team effectiveness (Cooke et al., 2013). In addition, unlike internalized knowledge states, team interaction in the form of communication is readily observable and can be examined over time, thus providing ready access to the temporal dynamics involved (Cooke, Gorman, and Kiekel, 2008; Gorman, Amazeen, and Cooke, 2010).

Another approach to team cognition, focused more on the development of shared problem models, is the macrocognition in teams model (Fiore et al., 2010b). This model is based upon a multidisciplinary theoretical integration that captures the cognitive processes engaged when teams collaboratively solve novel and complex problems. It draws from theories of externalized cognition, team cognition, group communication and problem-solving, and collaborative learning (Fiore et al., 2010a). It focuses on team processes supporting movement between internalization and externalization of cognition as teams build knowledge in service of problem-solving. Recently the model has been examined in complex contexts such as problem-solving for mission control, in which scientists and engineers were required to collaborate to understand and solve problems on the International Space Station (Fiore et al., 2014).

As with other interpersonal processes, interventions can improve cognitive interaction and ultimately team effectiveness. Training that exposes teams to different ways of interacting (Gorman, Cooke, and Amazeen, 2010), as well as team composition changes (Fouse et al., 2011; Gorman and Cooke, 2011), have been found to lead to more adaptive and flexible teams. Similarly, training or professional development designed to support knowledge-building activities has been shown to enhance collaborative problem-solving and decision-making, leading to improved effectiveness (Rentsch et al., 2010, 2014). These and other professional development approaches are discussed in more detail in Chapter 5.

Science teams and larger groups, like teams in general, are interdependent and require interaction to build new knowledge. They need to manage a range of technological and social factors to coordinate their tasks and goals effectively. Salazar et al. (2012) have proposed a model of team science, discussed later in this chapter, in which social integration processes support cognitive integration processes. These processes can help foster deep knowledge integration in science teams or larger groups.

Many of the features that create challenges for team science described in Chapter 1 introduce challenges to cognitive interaction, and, therefore, interventions that bolster cognitive interaction, such as professional development or training to expose teams to different ways of interacting, may be particularly helpful for science teams.

Team Climate

Climate represents shared perceptions about the strategic imperatives that guide the orientation and actions of team or group members (Kozlowski and Hults, 1987; Schneider and Reichers, 1983). It is always shaped by a particular team or organizational strategy. For example, if a team's goal is to innovate, the team may have a climate of innovation (Anderson and West, 1998); if the goal is to provide high-quality service, the team may have a service climate (Schneider, Wheeler, and Cox, 1992); if safety is critical for team or organizational success, the team or the larger organization may have a safety climate (Zohar, 2000).

Climate has been studied for over seven decades and the relationship of climate to important work outcomes is well established (e.g., Carr et al., 2003; Schneider and Barbera, 2013; Zohar and Hofmann, 2012).

Several types of interventions can shape team or group climate. For example, organizations communicate strategic imperatives through policies, practices, and procedures that define the mission, goals, and tasks for teams and larger groups within the organization (James and Jones, 1974). Team leaders shape climate through what they communicate to their teams from higher levels of management and what they emphasize to their team members (Kozlowski and Doherty, 1989; Schaubroeck et al., 2012; Zohar, 2000, 2002; Zohar and Luria, 2004). And team members interact, share their interpretations, and develop shared understandings of what is important in their setting (Rentsch, 1990).

Psychological Safety

Psychological safety is a shared perception among team members indicative of an interpersonal climate that supports risk taking and learning (Edmondson, 1999). The research on psychological safety has been focused primarily on its role in promoting effective error management and learning behaviors in teams (Bell and Kozlowski, 2011; Bell et al., 2012). Learning from errors (i.e., to identify, reflect, and diagnose them and develop appropriate solutions) is particularly important in science as well as in other teams charged with research and development or innovation (Edmondson and Nembhard, 2009), and therefore, fostering psychological safety may be uniquely valuable for science teams and larger groups. Although research on this process has not yet been summarized in a published meta-analysis, support for its importance is provided by a systematic stream of theory and research (e.g., Edmondson, 1996, 1999, 2002, 2003; Edmondson, Bohmer, and Pisano, 2001; Edmondson, Dillon, and Roloff, 2007).

Research on psychological safety has focused on the role of team leaders in coaching, reducing power differentials, and fostering inclusion to facilitate psychological safety, so that team members feel comfortable discussing and learning from errors and developing innovative solutions (e.g., Edmondson, 2003; Edmondson, Bohmer, and Pisano, 2001; Nembhard and Edmondson, 2006). Hall et al. (2012a) proposed that creating an environment of psychological safety is critical to lay the groundwork for effective transdisciplinary collaboration. Thus, the research base suggests that appropriate team leadership is a promising way to promote psychological safety, learning, and innovation in science teams and larger groups.

Motivational and Affective Team Processes

Key factors that capture motivational team processes—team cohesion, team efficacy, and team conflict—have well-established relations with team effectiveness.

Team Cohesion

Team cohesion—defined by Festinger (1950, p. 274) to be “the resultant of all the forces acting on the members to remain in the group”—is among the most frequently studied team processes. It is multidimensional, with facets focused on task commitment, social relations, and group pride, although this latter facet has received far less research attention (Beal et al., 2003). Our primary focus is on team task and social cohesion because that is where most of the supporting research is centered.

There have been multiple meta-analyses of team cohesion, with two of the more recent ones (Gully, Devine, and Whitney, 1995; Beal et al., 2003) being the most thorough and rigorous. Both papers concluded that team cohesion is positively related to team effectiveness and that the relationship is moderated by task interdependence such that the cohesion-effectiveness relationship is stronger when team members are more interdependent. For example, Gully et al. (1995) reported that the effect size for cohesion and performance was .20 when interdependence was low, but .46 when task interdependence was high. Because high task interdependence is one of the features that creates challenges for team science, fostering cohesion may be particularly valuable for enhancing effectiveness in science teams and larger groups.

Remarkably, although team cohesion has been studied for over 60 years, very little of the research has focused on antecedents to its development or interventions to foster it. Theory suggests that team composition factors (e.g., personality, demographics; see Chapter 4) and developmental efforts by team leaders (e.g., Kozlowski et al., 1996, 2009) are likely to play an important role in its formation and maintenance.

Team Efficacy

At the individual level, research has established the important contribution of self-efficacy perceptions to goal accomplishment (Stajkovic and Luthans, 1998). Generalized to the team or organizational level, similar, shared perceptions are referred to as team efficacy (Bandura, 1977). It influences the difficulty of goals a team sets or accepts, effort directed toward goal accomplishment, and persistence in the face of difficulties and challenges. The contribution of team efficacy to team performance is well established ($\rho = .41$) (Gully et al., 2002), across a wide variety of team types and work settings (Kozlowski and Ilgen, 2006). As with team cohesion, Gully et al. (2002) reported that team efficacy is more strongly related to team performance when team members are more interdependent ($\rho = .09$ when interdependence is low, and $\rho = .47$ when interdependence is high).

Antecedents of team efficacy have not received a great deal of research attention. However, findings about self-efficacy antecedents at the individual level can be extrapolated to the team level. These antecedents include individual differences in goal orientation (i.e., learning, performance, and avoidance orientation; Dweck, 1986; VandeWalle, 1997) and experiences such as enactive mastery, vicarious observation, and verbal persuasion (Bandura, 1977). To develop team efficacy, leaders may consider goal orientation characteristics when selecting team members, but these characteristics can also be primed (i.e., encouraged) by leaders. Similarly, leaders can create mastery experiences, provide opportunities for team members to observe others succeeding, and persuade a team that it is efficacious (see Kozlowski and Ilgen, 2006, for a review).

Team Conflict

Team or group conflict is a multidimensional construct with facets of relationship, task, and process conflict:

> Relationship conflicts involve disagreements among group members about interpersonal issues, such as personality differences or differences in norms and values. Task conflicts entail disagreements among group members about the content and outcomes of the task being performed, whereas process conflicts are disagreements among group members about the logistics of task accomplishment, such as the delegation of tasks and responsibilities (de Wit, Greer, and Jehn, 2012, p. 360).

Although conflict is generally viewed as divisive, early work in this area concluded that although relationship and process conflict were negative factors for team performance, task conflict could be helpful for information-sharing and problem-solving provided it did not spill over to prompt relationship conflict (e.g., Jehn, 1995, 1997). However, a meta-analysis by De Dreu and Weingart (2003) found that relationship and task conflict were both negatively related to team performance. A more recent meta-analysis (de Wit et al., 2012) has shown that the relationships are more nuanced. For example, all three types of conflict had deleterious associations with a variety of group factors including trust, satisfaction, organizational citizenship, and commitment. In addition, relationship and process conflict had negative associations with cohesion and team performance, although the task conflict association with these factors was nil. Thus, this more recent meta-analysis suggests that task conflict may not be a negative factor under some circumstances, but the issue is complex.

Group composition that yields demographic diversity and group faultlines or fractures is associated with team conflict (Thatcher and Patel, 2011). Because diverse membership is one of the features that creates challenges for team science introduced in Chapter 1, science teams and groups can anticipate the potential for conflict. Many scholars suggest that teams and groups should be prepared to manage conflict when it manifests as a destructive and counterproductive force. Two conflict management strategies can be distinguished (Marks, Mathieu, and Zaccaro, 2001)—reactive (i.e., working through disagreements via problem-solving, compromise, and flexibility) or preemptive (i.e., anticipating and guiding conflict in advance via cooperative norms, charters, or other structures to shape conflict processes) (Kozlowski and Bell, 2012).

Team Behavioral Processes

Ultimately, team members have to act to combine their intellectual resources and effort. Researchers have sought to measure the combined behaviors of the team members, or team behavioral processes, in several ways, including by looking at team process competencies and team self-regulation.

Team Process Competencies

One line of research in this area focuses on the underpinnings of good teamwork based on individual competencies (i.e., knowledge and skill) relevant to working well with others. For example, Stevens and Campion (1994) developed a typology of individual teamwork competencies with two primary dimensions (interpersonal knowledge and self-management knowledge) that are each assessed with a set of more specific subdimensions. Based on this typology, they also developed an assessment tool, although empirical evaluations of this tool have yielded somewhat mixed results (Stevens and Campion, 1999).

Others have focused on behavioral processes at the team level. Integrating many years of effort, Marks et al. (2001) developed a taxonomy of team behavioral processes focusing on three temporal phases: (1) transition involves preparation (e.g., mission, goals, strategy) before task engagement and reflection (e.g., diagnosis, improvement) after; (2) action involves active task engagement (e.g., monitoring progress, coordination); and (3) interpersonal processes (e.g., conflict management, motivation) are viewed as always important.

A recent analysis by LePine, Piccolo, Jackson, Mathieu, and Saul (2008) extended the Marks et al. (2001) taxonomy to a hierarchical model that conceptualized the discrete behavioral processes as first-order factors loading onto second-order transition, action, and interpersonal factors, which are then loaded onto a third-order, overarching team process factor. Their meta-analytic confirmatory factor analysis found that the first- and second-order processes were positively related to team performance (mostly in the range of ρ=.25 to in excess of .30.).

Team Self-Regulation

For teams focused on reasonably well-specified goals, team processes and performance can be related to the team's motivation and self-regulation, similar to models of the relationship between motivation and performance at the individual level. Feelings of individual and team self-efficacy, discussed above (Gully et al., 2002), are jointly part of a multilevel dynamic motivational system of team self-regulation. Team self-regulation affects how team members allocate their resources to perform tasks and adapt as necessary to accomplish goals (Chen, Thomas, and Wallace, 2005; Chen et al., 2009; DeShon et al., 2004). In addition, there is meta-analytic support for the efficacy of group goals for group performance (O'Leary-Kelly, Martocchio, and Frink, 1994; Kleingeld, van Mierlo, and Arends, 2011).

Finally, there is meta-analytic support (Pritchard et al., 2008) for the effectiveness of an intervention designed to increase team regulation by measuring performance and providing structured feedback—the Productivity Measurement and Enhancement System (ProMES; Pritchard et al., 1988). On average and relative to baseline, productivity under ProMES increased 1.16 standard deviations.

Measuring Team Processes

To assess team processes and intervene to improve them, team processes must be measured. Team process factors such as making a contribution to the team's work, keeping the team on track, and appropriately interacting with teammates have traditionally been measured through self or peer reports of team members (Loughry, Ohland, and Moore, 2007; Ohland et al., 2012).

Instruments relying on behavioral observation scales and ratings of trained judges have also been used to measure processes associated with collaborative problem-solving and conflict resolution as well as self-management processes like planning and task coordination (Taggar and Brown, 2001). Brannick et al. (1995) evaluated judges' ratings of processes of assertiveness, decision-making/mission analysis, adaptability/flexibility, situation awareness, leadership, and communication. The ratings were found to be psychometrically sound and with reasonable discriminant validity, though the importance of task context was also noted: that is, process needs to be assessed in relation to the ongoing task. "Team dimensional training" was developed to measure a set of core team processes of action teams (e.g., Smith-Jentsch et al., 1998) and has since been validated in numerous settings (e.g., Smith-Jentsch et al., 2008). Another approach that provides for context is the use of checklists of specific processes that are targeted for observation (Fowlkes et al., 1994).

Researchers have measured cognitive processes somewhat differently, relying typically on indirect knowledge elicitation methods such as card sorting to identify team mental models (Mohammed, Klimoski, and Rentsch, 2000) and assess their accuracy (e.g., Smith-Jentsch, Kraiger, Cannon-Bowers, & Salas, 2009). In addition, concept maps corresponding to team member mental models have been developed by instructing participants to directly create them (e.g., Marks, Zaccaro, and Mathieu, 2000; Mathieu et al., 2000) or by indirectly creating them through similarity ratings of pairs of concepts analyzed using graphical techniques such as Pathfinder (Schvaneveldt, 1990). Transactive memory systems focusing on team members' knowledge of what each member knows have been measured both via self-assessment (Lewis, 2003) and via communications coding (Ellis, 2006; Hollingshead, 1998). Cooke et al. (2000) reviewed different measurement approaches for measuring team mental models (including process tracing and conceptual methods), pointing out challenges related to knowledge similarity for heterogeneous team members and methods of aggregation.

Recent work in this area has focused on developing measures that are unobtrusive to the teamwork and can capture its complex dynamics (e.g., video recording, team work simulations, and sociometric badges; Kozlowski, in press). Communication data, for example, can be captured with relatively little interference and provides a continuous record of team interaction (Cooke and Gorman, 2009; Cooke, Gorman, and Kiekel, 2008). This research has identified changes in patterns of simple communication flow (who talks to whom) that are associated with changes in the state of the team (such as loss of situation awareness or conflict). These continuous methods provide a rich view of team process, not captured by static snapshots in time.

INTERVENTIONS THAT SHAPE TEAM PROCESSES AND EFFECTIVENESS

Table 3-1 identifies actions and interventions that have been found to influence team processes related to three aspects of a team—its composition, professional development, and leadership. This section and the associated three chapters that follow provide detail on each of these three aspects.

[Insert Table 3-1 around here]

Team Composition: Individual Inputs to Shape Team Processes

Team composition results from the process of assembling a combination of team members with the expertise, knowledge, and skills necessary for accomplishing team goals and tasks. At the individual level, the logic of staffing is based on selecting individuals with knowledge, skills, abilities, and other characteristics that fit job requirements. At the team level, staffing is more complex because one is composing a combination of members who must collaborate well, not merely matching each person to a well-defined job (Klimoski and Jones, 1995). Chapter 4 takes a detailed look at how team composition and assembly are related to team processes and effectiveness.

Professional Development to Shape Team Processes

Once a team has been assembled, its effectiveness can be facilitated by formal professional development programs (in the research literature, these are referred to as training programs). Although much of the research on team training has focused on programs developed for military teams (Swezey and Salas, 1992; Cannon-Bowers and Salas, 1998), these teams face many of the same process challenges as science teams and groups, resulting from features such as high diversity of membership, geographic distribution, and deep knowledge integration. Further evidence supporting training as an intervention to facilitate positive team processes is reviewed in Chapter 5, along with discussion of educational programs dedicated to preparing individuals for future participation in team science.

Leadership to Shape Team Processes

Research has shown the influence of leadership on team and organizational effectiveness. Most of this research, however, focuses on the leader, rather than the team, and measures the effectiveness of the leader based on individual perceptions rather than measuring team effectiveness. The leadership literature is also rich with theories of leadership, some of which seem particularly relevant for science teams and larger groups. There is also promising new work on the concept of shared leadership by all team members. Moreover, recent meta-analytic findings provide support for the positive relationship between shared leadership and team effectiveness (42 samples, $\rho = .34$; Wang, Waldman, and Zhang, 2014), suggesting that it may be a useful concept for science teams. Team science leadership is discussed further in Chapter 6.

CONNECTING THE LITERATURE TO TEAM SCIENCE

New Models of Team Science

Researchers have developed and begun to study models of science teams and effectiveness. Moving beyond traditional models of group development, such as Tuckman's (1965) phases of storming, norming, forming, and performing, these models incorporate elements specific to science teams and larger groups, such as deep knowledge in interdisciplinary teams, to meet scientific and societal goals. They provide different windows into team science and serve different purposes with respect to team science practice and policy. For instance, Hall et al. (2012b) proposed a model that serves as a heuristic for considering the broad research process. The model delineates four dynamic and recursive phases: development, conceptualization, implementation, and translation (see Box 3-2). Key team and group processes from the literature on teams and organizations are then linked to each of four phases. One of the unique contributions of this model is to highlight the breadth of collaborative and intellectual work that can be done in the early stages of developing a team science research project. Currently, such work in the development phase is often carried out hastily due to resource constraints. This part of the model helps to highlight the need for planning, institutional support, and funding specifically for the development phase. Overall, the model emphasizes key team and larger group processes that may, across the four phases, increase the comprehensiveness and sophistication of the science and effectiveness of the collaboration.

In contrast, Salazar et al (2012) presented a model that specifically focuses on enhancing a team's integrative capacity through the interplay of social, psychological, and cognitive processes (see Box 3-2). Hadorn and Pohl (2007) presented a model of the transdisciplinary research process that discusses elements of both research and integration processes. The three phases of the model include: (1) problem identification and structuring, (2) problem analysis, and (3) bringing results to fruition. This model is specifically designed for incorporating the community perspective (i.e., via "real world actors") and includes strategies linked to these phases. It draws heavily on a European perspective of transdisciplinarity, science policy, and sustainability research. Reid et al. (2009) and Cash et al. (2003) also discussed models of engaging and integrating knowledge from community stakeholders for sustainability. For instance, Cash et al. (2003) identified key mechanisms for information exchange, transfer, and flow that facilitate communication, translation, and mediation across boundaries in transdisciplinary team science projects.

Existing models of team science have primarily focused on specific aspects of research and knowledge integration processes, but work has recently begun on a team science systems map project that would provide a broader, holistic understanding of the system of factors involved in the context, processes, and outcomes of team science (Hall et al., 2014a). Such a map would aid in identifying possible leverage points for interventions to maximize effectiveness, as well as areas where further research is needed (see further discussion in Chapter 10).

BOX 3-2
Two Models of Team Science

In the first model, Hall et al. (2012b) proposed that transdisciplinary team science includes four phases: development, conceptualization, implementation, and translation:

- In the development phase, the primary goal is to define the relevant scientific and societal problem. Early in this stage, an informal group of scientists begins to "scope out" a research area and identify relevant areas of expertise. Team and processes critical for effectiveness at this stage include creating a shared mission and goals (i.e., shared mental models); developing critical awareness of the strengths and weaknesses of one's own and other disciplines; and developing an environment of psychological safety. An effective method for supporting these processes is to engage the group in creating a visual representation of the problem area, referred to as a "cognitive artifact," and updating this representation as the work proceeds.
- In the conceptualization phase, the group develops research questions, hypotheses, a conceptual framework, and a research design. Team processes that enhance effectiveness at this stage include developing shared language, such as by using analogies and lay language in place of disciplinary jargon; developing transactive memory (similar to non-science teams); and developing a transdisciplinary team orientation, which incorporates both the critical awareness described above and team self-efficacy, as described earlier in this chapter.
- In the implementation phase, the primary goal is to carry out the planned research. The membership of the team or larger group stabilizes as the core participants develop routines, such as frequency of meeting. At this stage, developing a more

extensive team or group transactional memory, including shared understanding of how things get done (taskwork) and how interactions occur (teamwork), enhances effectiveness. Conflict management is also essential to avoid conflicts that could otherwise derail the development of team processes. Another critical process at this stage is team learning, including reflection on action, similar to the team regulation approaches described above, while at the same time, scientific effectiveness is enhanced through continued efforts to promote shared language and mental models.

- In the translation phase, the primary goal is to apply research findings along the research continuum towards address real-world problems. As the team or group membership evolves accordingly, developing shared understandings of team goals and roles (i.e., shared mental models and transactive memory) among old and new members aids effectiveness. These processes are especially critical as community or industry stakeholders may become engaged at this stage, potentially creating communication challenges even greater than those involved in communicating across disciplines.

Hall et al. (2012b) proposed that the four-phase model can serve as a roadmap as scientists and stakeholders move through the four phases, and as a guide to evaluation of, and quality improvement for, team science projects.

Salazar, et al (2012) proposed a second model that links the performance of an interdisciplinary or transdisciplinary science team or larger group to its "integrative capacity" defined as the ability to (Salazar et al, 2012, p. 22) "work across disciplinary, professional, and organizational divides to generate new knowledge…through the continuous interplay of social, psychological, and cognitive processes within a team."

The authors proposed that integrative capacity allows a team or larger group to overcome barriers to integration that may arise due to several factors, such as team members' strong identification with their individual disciplines, differing conceptualizations of the team goal and the research problem, and geographic dispersion. Thus, the model directly addresses the challenges emerging from several of the key features including high diversity of membership, deep knowledge integration, and geographic dispersion.

The authors identified three pathways that comprise a team's integrative capacity:

- First, social integration processes, including the development of shared understandings of the project goal (i.e., shared mental models); communication practices facilitated by shared leadership; and collective understanding of all team members' perspectives and expertise (i.e., transactive memory) are the basis for cognitive integration.
- Second, these social processes lead to emergent states such as trust and positive emotions, which in turn facilitate cognitive integration. Formal interventions, norms, and technological infrastructure can support development of these social processes and emergent states. For example, structured interventions can be used to encourage team members to ask one another about their expertise, supporting development of transactive memory.
- Third, these social processes and emergent states facilitate the cognitive processes of knowledge consideration, assimilation, and accommodation, leading, in turn, to

continued growth of the team's integrative capacity. Feelings of identity with the interdisciplinary science team encourage each team member to thoughtfully consider other team members' knowledge and to either assimilate the new knowledge into his or her own thinking or accommodate it to develop new ways of thinking. Both assimilation and accommodation require reflexivity, or team members' ability to reflect on and improve their own and the team's knowledge, strategy and processes. Reflexivity is similar to the process of team self-regulation discussed earlier in this chapter, which has been shown to help teams adapt performance as necessary to carry out tasks and accomplish goals.

While further research is needed to test these two new models of team science, they begin to illuminate how science team processes are related to scientific and translational effectiveness. They also help to address the challenges for team science created by the seven features introduced in Chapter 1.

End of Box 3-2

Features that Create Challenges for Team Science and Team Processes

Most of the key features that create challenges for science teams and larger groups have direct impacts on team processes:

- As noted by both Hall et al. (2012b) and Salazar et al. (2012), science teams or larger groups with highly diversity of membership (feature #1) face challenges particularly in the area of team process. Communication across scientific disciplines or university boundaries, for instance, may prove difficult.
- Deep knowledge integration (feature #2) is required to achieve the objectives of interdisciplinary or transdisciplinary team science projects, yet also points to team process as a central mechanism for effectiveness. Strategies and interventions to foster positive team processes (described more fully in Chapters 4, 5, and 6) are critical for effective collaboration within science teams and larger groups that have diverse membership and seek to foster deep knowledge integration.
- The research on how team process influences effectiveness described in this chapter has primarily been based on relatively small teams of 10 or less, as few researchers have attempted to conduct empirical team research on larger groups (feature #3). As noted in Chapter 1, most science teams include 10 or fewer members, suggesting that the findings in this chapter are relevant to science teams. Although it is unclear whether the findings scale to larger groups, the committee assumes that increasing size poses a challenge to group processes and ultimately group effectiveness.
- Large science groups composed of subteams that may be misaligned with other subteams (feature #4), as well as teams or groups of any size with permeable boundaries (feature #5), may also be less cohesive than other teams or groups. When team or group membership changes to meet the changing goals of different phases of a transdisciplinary research project, leaders need to make renewed efforts to develop shared understandings of the project goals and individual roles (Hall et al., 2012b). Such efforts, along with other leadership strategies described in Chapter 6, can help to address these features.

- Geographic dispersion (feature #6) limits face-to-face interaction and thereby places a toll on cognitive interaction in a team or group. Some ways to address this particular challenge are described in Chapter 7.
- High task interdependence (feature #7) is often exaggerated in science teams or groups due to the complex demands of scientific research that may involve sharing highly sophisticated technology or carrying out tasks with experts from a different discipline. Increasing task interdependence creates increasing demand for such team processes as shared mental models (shared understanding of research goals and member roles) and transactive memory (knowledge of each team members' expertise relevant to the research goals).

The seven features create challenges through the processes in which science teams engage. The features of diversity, large size, permeable boundaries, and geographic dispersion push team or group members apart, impacting cohesion and conflict and generally challenging cognitive interaction. On the other hand, features such as the need for deep knowledge integration in interdisciplinary and transdisciplinary team or groups and high task interdependence demand enhanced team processes. Thus these features demand high-quality team processes while also posing barriers that thwart them, creating a team process tension.

SUMMARY AND CONCLUSION

Based on its review of the robust research on teams in contexts outside of science and the emerging research on team science, the committee concludes that team processes (such as shared understanding of goals and team member roles, team cohesion, and conflict) are related to effectiveness in science teams and larger groups, and that these processes can be influenced. The committee assumes that research-based actions and interventions developed to positively influence these processes and thereby increase effectiveness in contexts outside of science can be extended and translated to similarly increase the effectiveness of science teams and larger groups. Actions and interventions targeting team composition, team leadership, and team professional development are discussed further in the following chapters.

<u>Conclusion</u>. *A strong body of research conducted over several decades has demonstrated that team processes (e.g., shared understanding of team goals and member roles, conflict) are related to team effectiveness. Actions and interventions that foster positive team processes offer the most promising route to enhance team effectiveness; they target three aspects of a team: team composition (assembling the right individuals), team professional development and team leadership.*

TABLE 3-1 Team Processes Related to Team Effectiveness: Interventions and Support

Process	***Interventions***	***Empirical Support for Interventions***
Team Mental Models	▪ Training ▪ Leadership ▪ Shared experience	▪ Systematic theory, method development, and research ▪ Meta-Analytic Support (DeChurch & Mesmer-Magnus, 2010)
Transactive Memory	▪ Face to face interaction ▪ Shared experience	▪ Theory, measurement, and research findings ▪ Meta-Analytic Support (DeChurch & Mesmer-Magnus, 2010)
Cognitive Team Interaction	▪ Training ▪ Team Composition	▪ Theory, measurement, and research findings (Gorman, Cooke, & Amazeen, 2010; Gorman & Cooke, 2011)
Team Climate	▪ Strategic imperatives; Team Mission/Goals; Policies, Practices, and Procedures ▪ Leadership ▪ Team Member Interaction	▪ Body of systematic theory, method development, and research (Carr et al., 2003; Schneider and Barbera, 2013; Zohar & Hofmann, 2012)
Psychological Safety	▪ Leader Coaching, Inclusion ▪ Positive Interpersonal Climate	▪ Systematic Empirical Support

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Table 3-1 (continued)

Process	***Interventions***	***Empirical Support for Interventions***
Team Cohesion	▪ Antecedents Not Well Specified ▪ Theory = Team Composition ▪ Theory = Leadership	▪ Systematic Empirical Support ▪ Meta-Analytic Support (Beal et al., 2003; Gully et al., 1995)
Team Efficacy	▪ Mastery Experiences ▪ Vicarious Observation ▪ Verbal Persuasion ▪ Theory = Leader Behavior	▪ Systematic Empirical Support ▪ Meta-Analytic Support (Gully et al., 2002)
Team Conflict	▪ Team Composition, Faultlines ▪ Conflict Management Skills	▪ Empirical Support ▪ Meta-Analytic Support (De Dreu & Weingart, 2003; Thatcher & Patal, 2011; de Wit et al., 2012)
Process	Interventions	Support
Team Process Competencies	▪ Training ▪ Theory = Leadership	▪ Empirical Support ▪ Meta-Analytic Support (LePine et al., 2008)
Team Regulation	▪ System Design ▪ Theory = Leadership	▪ Body of Systematic Theory and Research ▪ Meta-Analytic Support (Pritchard et al., 2008)

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