Collective Failure: The Emergence, Consequences, and Management of Errors in Teams

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On the evening of March 5, 2000, Southwest Airlines Flight 1455 overran the end of the runway while landing at Burbank-Glendale-Pasadena Airport. The plane broke through a metal blast fence at approximately 40 knots, skidded across Hollywood Way, and came to rest in front of a Chevron gasoline station. Of the 142 passengers on board, 2 received serious injuries, 42 received minor injuries, and the aircraft was written off. This was the first major accident in the 33 year history of Southwest and the question was quickly raised as to what went wrong. An investigation by the National Transportation Safety Board (NTSB) revealed that the probable cause of the accident was a fast, steep, and unstabilized approach (National Transportation Safety Board, 2002). The aircraft descended at an angle 3 or 4 degrees steeper than the typical flightpath and touched down 2,150 feet down the runway traveling 44 knots over the target airspeed. The descent was so steep that it sounded automated “sink rate” warnings in the cockpit, yet both the captain and first officer ignored the warnings. The captain later reported that he knew he was not “in the slot” required for a normal landing and should have performed a go-around maneuver, but said that he became “fixated on the runway.” The first officer indicated in postaccident interviews that he was also aware they were “out of the slot,” but did not mention it because he believed the captain was taking corrective action. Southwest later fired both pilots and admitted that their actions in the incident were negligent.

In 1993, NASA started the Mars Surveyor program with the goal of conducting a series of missions to explore Mars. One of the missions added to the program in 1995 was the Mars Climate Orbiter (MCO), which was designed to carry instruments to study the planet’s surface, atmosphere, and weather. The MCO was launched December 11, 1998 and traveled 416 million miles over the next 9 ½ months to reach Mars. However, shortly after firing its main engine to achieve elliptical orbit around Mars, radio contact was lost and no further signal was ever received from the spacecraft. An investigation later revealed that a simple software error led to the spacecraft entering the Martian atmosphere at a lower than expected trajectory and its likely destruction due to atmospheric friction (Mars Climate Orbiter Mishap Investigation Board, 1999). Specifically, the navigation team at the Jet Propulsion Laboratory used metric units in its calculations, but the design and manufacturing team at Lockheed Martin provided important acceleration data in English units (Hotz, 1999). The result was that the effect of the thrusters was underestimated by a factor of 4.45 – the required conversion factor from force in pounds to Newtons – and the spacecraft drifted off course. A NASA official was later quoted as saying, "This was not a failure of Lockheed Martin. It was systematic failure to recognize and correct an error that should have been caught" (Hotz, 1999, p. A-1).

A fourth-year medical student on rotation in the pediatric intensive care unit (PICU) was invited to observe the operative repair of a congenital heart lesion (Wachter, 2005). As the surgical team prepped the patient for surgery, the student was surprised to see one of the team members insert a catheter without first performing a "sterile prep." However, the student was new to the PICU and assumed different procedures are used with pediatric patients, so she did not mention the incident to any of the team members. Three days later, the patient developed an infection and, while on rounds, the student presented the account of the catheter placement in the operating room. After rounds, the student was approached by two attendings. One commented that the information about the catheter should not have been presented during rounds because the patient's family may overhear. The second attending told the student the information should have been presented in the operating room. Neither attending commended the student for bringing the incident to the attention of the team (Wachter, 2005).

Over the past two decades, there has been an ongoing shift from work organized around individual jobs to team-based work systems (Kozlowski & Bell, 2003). As the nature of work has grown more complex and dynamic, organizations have turned to teams to perform tasks that exceed the capabilities of a single individual. Because they have the potential to serve as self-correcting performance units (Hackman, 1993), teams are also being used in organizations that emphasize quality and high reliability. Yet, as the examples above illustrate, teams are not infallible. In fact, the potential for teams to fail is very real, because they are often used in situations characterized by a high risk of errors (e.g., aviation, medicine, military) and in situations where even minor errors can have severe consequences (Salas, Cooke, & Rosen, 2008). As Salas, Kosarzycki, Tannenbaum, and Carnegie (2005, p. 98) state, "On the one hand, it is clear that teams can accomplish great things, but it is equally apparent that subfunctioning teams have the potential to fail spectacularly." Fortunately, most errors that occur in teams are unspectacular or are remedied before they lead to disaster. More minor errors are nevertheless important because they can impede team effectiveness, can stimulate team learning, and represent warning signs to potentially larger and more consequential errors (Edmondson, 2004).

Although it is widely acknowledged that teams can and often do fail, the conditions that give rise to errors in teams, the implications of these errors for team effectiveness, and the ability of teams to prevent and manage errors are not well understood (Bauer & Mulder, 2007; Tjosvold, Yu, & Hui, 2004). This may be due, in part, to the fact that errors in teams rarely have simple causes or consequences. Team performance is influenced by factors occurring not only at the team level (e.g., communication, coordination) but also at levels above (e.g., culture, climate) and below (e.g., individual performance), which can make it difficult to determine the root cause of a team failure (Rosen et al., 2008). Also, although errors often have negative consequences for team performance, they represent an important stimulus of team learning and a foundation for continuous improvement and adaptive capabilities. Accordingly, to understand the impact of errors on the effectiveness of a team over time, it is important to look more closely at how teams manage errors when they occur.

The goal of the current chapter is to examine the emergence, consequences, and management of errors in teams. We begin by discussing the origin and emergence of errors in teams. We argue that errors in teams can originate at both the individual and collective level and suggest this distinction is important because it has implications for how errors propagate within a team. We then consider the paradoxical effects of errors on team performance and team learning. This discussion highlights the importance of error management in teams so that errors can prompt learning while at the same time mitigating their negative consequences. Thus, we focus significant attention on the challenge of error prevention and error management in teams and highlight numerous factors that can influence these processes. We conclude the chapter with a discussion of important research gaps and outline an agenda for future work in this area.

Origin and Emergence of Errors in Teams

Hofmann and Frese (this volume) define errors as actions that "unintentionally fail to achieve their goal where this failure was potentially avoidable." This definition highlights several widely accepted and fundamental properties of errors. First, an error occurs when there is a deviation from something else, namely some external goal, standard, or desired behavior. Second, errors are unintended, which differentiates them from intentional deviations from standards or goals (i.e., violations). For instance, an error can occur when there is a failure to execute an intended action or plan or when the plan itself is inappropriate or inadequate to achieve the intended outcome (Rasmussen, 1986; Reason, 1990). Third, errors are potentially avoidable. That is, the error cannot be attributed to the intervention of some chance agency. This property distinguishes errors from the concept of risk, where one knowingly accepts some probability of failure (Hofmann & Frese, this volume).

Human error is unavoidable, particularly in today's complex and dynamic work environments. Recognizing this, organizations have adopted a variety of strategies to mitigate the effects of human error, including training, human factors engineering, and work design. One specific approach is to design work around teams, because team members can serve as redundant systems to help catch one another's mistakes and provide support when needed (Salas, Wilson, Murphy, King, & Salisbury, 2008). However, researchers have also suggested that placing a task in a team context may have little impact on error rates for a number of reasons, including social distractions and social loafing (Hollenbeck, Ilgen, Tuttle, & Sego, 1995). Although there is evidence that teams sometimes make fewer mistakes than individuals (Baker, Day, & Salas, 2006; Foushee, Lauber, Baetge, & Acomb, 1986), it is also clear that errors are a common occurrence in teams, even in high reliability settings (Edmondson, 2004; Thomas, 2004).

To understand the nature of errors at the collective level, it is important to consider the origin of errors in teams. Errors within teams can originate and manifest at both the individual and collective levels of analysis, and we suggest that the level at which an error originates has important implications for how it propagates through the team and the ability of the team to identify and manage the error. In the sections that follow, we first consider individual error within the context of teams, and then extend our examination to the collective level.

Individual Error in Teams

Hofmann and Frese (this volume) develop an integrative error taxonomy, which is based on the fundamental premise that behavior in organizations is goal directed. Their taxonomy is based on action theory (Frese & Zapf, 1994) and its basic structure is similar to other prominent error taxonomies in the field, such as Reason's (1990) generic error-modeling system (GEMS) and Rasmussen's (1982) skill-knowledge-rule framework. In particular, they argue that execution of a goal requires a number of actions and sub-actions or tasks, as well as higher order regulation processes that coordinate and monitor the cascading sequence of actions. This hierarchy of actions and regulatory processes can be decomposed into four different levels, with different types of errors occurring at each level. For example, the lowest level of regulation is the sensorimotor level, which involves the non-conscious execution of skill-based scripts or automatic movement sequences. Errors at this level arise from stereotyped and automatic movements, such as typing an incorrect key. In contrast, the conscious, or intellectual, level of regulation involves active cognitive processing and the development of goals and plans. Errors at this level, referred to as knowledge errors, occur when a person develops an inappropriate or inadequate goal or plan due to resource constraints (e.g., inability to access prior knowledge) or incomplete or incorrect knowledge. In between the non-conscious and conscious levels of regulation is the level of flexible action patterns, which involves well-known actions that are triggered by environmental cues and adapted to the situation (Hofmann & Frese, this volume). Errors at this level typically occur when a person misclassifies a situation and applies a rule (i.e., plan) that is inappropriate or deficient given the circumstances. Finally, there is an overarching level of regulation, the heuristic level, which involves the general approaches, or meta-cognitive strategies, that individuals apply toward goal accomplishment. Errors at this level arise in the processes that individuals use to formulate goals, conduct information searches, develop plans, and monitor and process feedback.

Although this taxonomy focuses on errors that affect individual goal achievement, individual error can also lead to collective failure. Kozlowski, Gully, Nason, and Smith (1999) described how team member errors, if undetected and uncorrected, can "propagate throughout the network if they are sent to a central role or along a critical path" (p. 272). For example, on July 3, 1988 the USS Vincennes mistakenly shot down an Iranian Airbus, killing 290 civilians. Although multiple factors contributed to this disaster, identification errors committed by the radar console operators were paramount (Fisher & Kingma, 2001). The operators misidentified the Airbus A300 as an Iranian Air Force F-14 and mistakenly claimed the aircraft was descending when it was actually climbing. These information processing errors (i.e., mapping errors; see Hofmann & Frese, Table 1) by the individual operators permeated throughout the command and control team and ultimately facilitated the erroneous decision to shoot down the aircraft. As another example, on April 26, 1994, China Airlines Flight 140 crashed on its approach to land in Nagoya, Japan, killing 264 of the 271 individuals on board. An investigation revealed that while performing the approach the first officer inadvertently pressed the take-off go around (TOGA) button located on the forward edge of the throttles, which increases thrust to take-off levels. Subsequent efforts by the crew to correct the situation resulted in a steep climb, at which point the plane stalled and crashed. Thus, the sensorimotor error committed by the first officer triggered a sequence of actions by the crew, many of which were inappropriate given the circumstances, which ultimately doomed the flight.

In both of the examples provided above, individual error was a primary cause of the failure of the team. However, these two examples also highlight the different ways in which individual error can propagate in team settings. In the case of the Vincennes, the operators' errors led directly to the erroneous decision to shoot down the aircraft. Thus, the causal chain linking the individual error and team failure was short and direct. However, in the case of the China Airlines flight, the first officer's inadvertent press of the TOGA button did not directly cause the accident. Rather, the error triggered a flawed recovery operation by the crew, which led the aircraft to stall and crash. Thus, the first officer's error was a precipitating event that was distally linked to the accident through a subsequent chain of errors committed by the crew. Whether an error serves as a direct or indirect cause of team failure may have important error management implications. For instance, when an error has indirect consequences, a team may have more time and opportunity to identify and trap the mistake before it impacts other parts of the system.

Interestingly, both examples involve teams performing in complex task environments characterized by highly interdependent workflow arrangements in which members must diagnose, problem solve, and/or collaborate simultaneously (Van de Ven, Delbecq, & Koenig , 1976). Some authors have argued that team members should be better able to catch each other's mistakes when interdependence is high, but it may depend on the nature of that interdependence. Salas, Sims, and Burke (2005), for example, argue that mutual performance monitoring is critical to catching mistakes prior to or shortly after they occur and suggest that this process is easier in collaborative tasks than in coordination tasks. Similarly, Druskat and Pescosolido (2002) argue that heedful interrelating, or an awareness of team member interdependence, increases a team's capability to reduce process errors and adapt to unexpected events. Consistent with these arguments, we suggest that team failure that is rooted in individual error may occur more often in situations characterized by low levels of interdependence. For example, in situations where a team is composed of distributed experts who perform their work separately and then combine it to form the final product (i.e., pooled/additive work arrangements), team members will find it more difficult to monitor and evaluate fellow members' work. In contrast, in situations where there is a high level of workflow interdependence (i.e., reciprocal or intensive workflow arrangements) accompanied by a shared understanding of the task and team responsibilities, team members will have greater opportunity and capacity to identify and correct individual errors before they impact team performance (Salas, Sims et al., 2005).

Insert Figure 1 about Here

Collective Error

Although sometimes the product of individual error, it is more often the case that team failure is due to errors that occur at the collective level, most commonly a breakdown in internal team processes (Sims & Salas, 2007). Research has shown that a majority of aviation accidents are due to failures in coordination among the crew (Freeman & Simmon, 1991) and the medical community has identified communication failures as the leading cause of inadvertent patient harm (The Joint Commission). Yet, teams often attribute errors to individual causes, which has important implications for error prevention and management. Leonard, Graham, and Bonacum (2004), for instance, note that in medicine there is a deeply embedded belief that quality of care is the result of being well trained and trying hard. The result is that errors are typically viewed as personal failures, rather than a failure of the team or larger organizational system, and are therefore often not reported or openly discussed.

Hofmann and Frese (this volume) argue that both individuals and collectives engage in functionally equivalent action cycles (cf., DeShon, Kozlowski, Schmidt, Milner, & Wiechamnn; Kozlowski & Bell, 2008) and we should be able to observe similar types of collective errors at the different levels of action regulation (with the exception of sensorimotor errors which are inherently individual level). Although errors at the individual and collective levels may be functionally similar (i.e., have similar effects or outputs), they differ structurally (Morgeson & Hofmann, 1999). That is, the processes that produce the functional outcomes differ across levels; at the individual level they are intrapersonal and at the collective level they are interpersonal. For example, Gersick and Hackman (1990) propose that teams often develop habitual routines, which exist "… when a group repeatedly exhibits a functionally similar pattern of behavior in a given stimulus situation without explicitly selecting it over alternative ways of behaving" (p. 69). Although habitual routines can yield functional benefits (e.g., save time and energy), when a group fails to recognize a novel situation or notice changes in a familiar situation it risks engaging in a habitual routine when an alternative response is needed. Thus, habitual routines can lead to dysfunction because the team miscodes the situation and performs a correct behavior in the wrong situation. These dysfunctional habitual routines are functionally similar to individual habit errors that occur at the level of flexible action patterns. Yet, they are structurally different because they represent patterns of behavior or interactions (interpersonal) rather than individual action (intrapersonal) (Kozlowski & Klein, 2000). Also, habitual routines are maintained through socio-emotional factors that exist within groups, such as social entrainment and group norms, whereas habit errors are perpetuated by cognitive biases (e.g., frequency-gambling, similarity matching) (Reason, 1990).

The interpersonal processes that underlie collective error can occur at the dyadic level or the team level. Consider the vignette on Southwest Airlines Flight 1455 that opened this chapter. On the surface it may appear that this accident was caused by the actions of the captain, who was the pilot flying on the approach. However, a closer examination reveals the accident was rooted in errors that occurred at the dyadic level, in the interaction between the captain and first officer. Both the captain and first officer were aware that the aircraft was not "in the slot," but neither of the pilots mentioned the deviation from normal operations. When the automated warnings sounded in the cockpit, the captain stated, "that's all right" and there was no further discussion of the issue (National Transportation Safety Board, 2002). The lack of communication in the cockpit led to a low level of situation awareness, such that the captain became fixated on the runway and the first officer incorrectly assumed the captain was taking corrective action. In their analysis of 300 civilian aviation incident reports, Jentsch, Barnett, Bowers, and Salas (1999) found that the loss of situation awareness by the flight crew represented the primary error committed in approximately half of the mishaps. Further, the authors found that when the captain was the pilot flying the plane, the first officer tried to correct the error in only 30% of the incidents. In the Southwest case, the loss of situation awareness resulted in neither the captain nor the first officer recommending a go-around maneuver, which is the airline's standard operating procedure when an aircraft is determined to be "out of the slot." Since both interacting parties contributed to the failure, the accident represents a collective failure rather than the failure of a single individual (Hofmann & Frese, this volume). Although this case focuses on a two-person crew, errors can originate at the dyadic level in larger teams as well. Consider, for example, teams characterized by a sequential workflow arrangement, in which work and activities flow undirectionally from one member to another (Bell & Kozlowski, 2002). Under these conditions, collective failure is likely to stem from errors that originate not at the collective level but rather at the dyadic level, such as a breakdown in coordination or communication as work transitions from one member to the next.

When teams are engaged in more collaborative and interdependent work, however, collective errors are likely to originate at the team level. Pearsall, Ellis, and Bell (2008), for example, demonstrate how errors in a team's transactive memory behaviors can impact team performance. Transactive memory is a group-level shared system for encoding, storing, and retrieving information, which combines the knowledge possessed by each team member with a collective awareness of who knows what (Wegner, 1987). Transactive memory develops and operates in teams through the communication of expertise-specific information between team members. In their study of 69 command and control teams characterized by a high level of task interdependence, Pearsall et al. (2008) found that errors often occurred in these communication behaviors, primarily as members attempted to update the directory of expertise in the team or allocate information to their teammates. For instance, team members frequently shared inaccurate task information and sent important information to the wrong person in the team. The authors found that the errors had a negative effect on team performance by creating deficiencies in transactive memory cognitions and mental model accuracy. The errors in transactive memory behaviors represent an example of a collective mapping error, because they involve information being processed and integrated incorrectly within the team (Hofmann & Frese, this volume). Not only do the errors originate at the team level but they also manifest in the collective knowledge structures (i.e., transactive memory cognitions, mental models) that exist within the team.

Although team errors can originate at both the dyadic and collective levels, the frequency of error occurrence may vary across the two levels. Researchers have noted that intra-team processes increase in complexity with more team members (Kozlowski & Bell, 2003). For example, research has found that larger teams are more likely to experience coordination problems that interfere with performance (Lantané, Williams, & Harkins, 1979). Thus, errors in teamwork (e.g., coordination, communication) may be more likely to occur in more intensive interactions than in unidirectional or bidirectional dyadic interactions. At the same time, however, intensive teamwork arrangements that involve multiple team members may provide greater opportunity for teams to detect, capture, and correct errors. As noted earlier, errors in teams often arise due to a breakdown in teamwork, but teamwork processes, such as mutual performance monitoring and backing up behavior, allow teams to create redundant systems that prevent and manage errors (Burke, Salas, Wilson-Donnelly, & Priest, 2004; Foushee et al., 1986). In dyads these redundant systems are limited and errors may be more likely to slip through undetected. Future research should examine the frequency with which errors in teams originate at the individual, dyadic, and team levels and the corresponding implications for error detection and correction within teams.

The Effects of Errors on Team Learning

Errors, by definition, are actions that fail to achieve their goal, which implies that they should have negative implications for team performance. Indeed, the cases discussed above demonstrate how errors can lead to team performance failures, sometimes with disastrous consequences. This suggests that teams should strive to prevent errors if they are to achieve optimal performance. However, research conducted over the past decade has revealed that errors are also an important stimulus of team learning and, as such, are critical to team performance improvement efforts (Edmondson, 2004; Wilson, Burke, Priest, & Salas, 2005). Wilson, Goodman, and Cronin (2007, p. 1044) define group learning as “a change in the group’s repertoire of potential behavior” and argue that the learning process in groups consists of the *sharing*, *storage*, and *retrieval* of group knowledge, routines, or behavior. To better understand the role of errors in team learning, we consider the potential effects of errors on each of these three group learning processes.

Sharing

Wilson et al. (2007, p. 1044) define sharing as, "the process by which new knowledge, routines, or behavior becomes distributed among group members and members understand that others in the group possess that learning." As a group construct, they argue that group learning takes place when members possess some new knowledge, routine, or behavior, *and* there exists an understanding that others in the group have the same knowledge and it is a property of the group. Because knowledge acquisition occurs at the individual level, the process of sharing transfers new knowledge to other group members and serves to legitimate the knowledge for the group. The process of knowledge sharing is a key component of most cognitively-oriented theories of team learning. For example, Ellis and Bell (2005) argue that collaboration, which includes the sharing of information, critical discussion, and insight within the team, is a critical condition for team learning. They suggest that team members must collaborate effectively with one another to share their knowledge, experience, or ideas with their teammates.

Errors may have several implications for knowledge sharing within teams. First, errors highlight potential pitfalls and error prone areas of a task, which in turn increases understanding of a system and facilitates the development of more accurate and complete mental models (Frese et al., 1988). Thus, errors may influence the content or quality of the information that is shared within a team and facilitate the development of more comprehensive shared mental models. Second, errors tend to be novel and unexpected events and therefore often involve a surprise reaction, which can induce mindfulness and stimulate learning (Bell & Kozlowski, 2009). In groups or teams, the surprise of an error may lead members to reflect on their performance, engage in collective sensemaking, and share knowledge. Bauer and Mulder (2007), for example, studied the learning activities of nurses after the experience of an error episode. After committing an error, they found that nurses often engaged in socially orientated learning activities, such as exchange with more experienced persons, joint root cause analysis, and the search for a new solution. The nurses emphasized the exchange with colleagues and supervisors as well as discussions in team meetings as critical activities for learning from errors.

Although errors may spur social exchange among team members, for knowledge sharing to be effective several subprocesses must take place. Specifically, a group must focus attention on the information that is to be learned, develop a shared understanding of the specific learning, and reach a shared understanding of how the new knowledge will be used in the future (Wilson et al., 2007). Yet, a number of individual, team, and organizational barriers can make it difficult for teams for fully engage in these processes. For example, team members may resist focusing on failure because doing so presents a threat to their self-esteem or may avoid revealing or discussing errors with colleagues for fear of being perceived as incompetent and losing valued organizational rewards (e.g., promotions, bonuses) (Cannon & Edmondson, 2001). One strategy for overcoming these barriers is to use formal processes to initiate and structure the analysis and discussion of errors within a team. In their theory of dynamic team leadership, Kozlowski and colleagues (Kozlowski, Gully, McHugh, Salas, & Cannon-Bowers, 1996; Kozlowski, Watola, Jensen, Kim, & Botero, 2009) describe how team leaders should monitor team performance and then lead the team in collective reflection and process feedback to promote learning by identifying errors, diagnosing them, and developing ways to improve individual and team performance. Salas, Klein et al. (2008) discuss the importance of debriefs or after-action reviews in the medical community. They state, "The debriefing process is used to allow individuals to discuss individual and team-level performance, identify errors made, and develop a plan to improve their next performance" (p. 519). Formal debriefs or audits should be used to not only discuss failures but also to examine "near misses," which can hold important lessons for preventing future errors (Wilson et al., 2005). Although formal processes can provide a forum for the sharing of knowledge gained from errors, effective knowledge sharing requires a supportive interpersonal climate. We discuss the influence of climate on error management in teams in more detail later in this chapter.

In this section, we have examined how performance errors may stimulate knowledge sharing in teams. However, errors may also occur *during* the team learning process, with potentially more negative consequences. In the study by Pearsall et al. (2008) discussed earlier, for example, the most common error in teams' transactive memory behaviors involved team members incorrectly sharing knowledge with their teammates, and these directory updating errors had a negative effect on team cognitions and performance. Future research should examine how errors that occur during the sharing, storage, and retrieval processes impact team learning and performance.

Storage

For group learning to occur, new knowledge must not only be shared within the team but it must also be stored and retained so that it can be exploited over time (Wilson et al., 2007). Groups have access to a wide range of storage repositories, including the memories of group members (i.e., transactive memory), information technology (e.g., databases, expertise systems), and structural repositories such as standard rules and procedures. Wilson et al. (2007) argue that the effectiveness of these different group repositories for storage and retrieval may depend on the type of knowledge being stored. Specifically, they suggest that explicit knowledge can be stored in any of the three types of repositories, but tacit knowledge may be more easily stored and retrieved in human memory systems.

Unfortunately, very little research has focused on group-level storage, which makes it difficult to determine precisely how errors may influence this feature of group learning. However, research conducted at the individual-level of analysis suggests that errors may impact both the content and process of group-level storage. As discussed above, errors can enhance the coherence and breadth of individuals' knowledge structures (Bell & Kozlowski, 2009). At the collective level, errors may have similar effects on the depth and breadth of knowledge stored in a team's repositories. For example, Tucker, Nembhard, and Edmondson (2006) argue that teams can engage in two types of learning activities. The first is "learn-what," which describes learning activities aimed at identifying best practices. The second type is "learn-how," which refers to learning activities that are aimed at understanding how and why a particular practice works so that it can be adapted to different situations. They suggest that learn-how occurs when teams engage in trial-and-error experimentation and reflect on their actions, including the mistakes that they made. Similarly, the team compilation model proposed by Kozlowski et al. (1999) suggests that teams can engage in the exploration of different structures or ways of performing their task under different situational demands to build their repertoire. As they state, "Adaptive teams will have created a repertoire of networks for different situations as well as corresponding indicators that signify when a switch in configuration must occur" (p. 273).

In addition to influencing the content of information stored in memory, errors may also prompt important storage processes in groups. Wilson et al. (2007) discuss how elaborative processing can improve storage through the enhancement of retrieval cues. For example, group discussion can serve as a form of elaboration or practice as the team considers how to respond to future problems or challenges. As discussed earlier, research has found that errors can prompt social exchange as individuals seek information and engage in joint problem-solving. In addition, research on learning has shown that when individuals engage in exploratory learning and make errors, they engage in more effortful processing of information and acquire knowledge at a higher level of regulation (Frese & Zapf, 1994). In the context of teams, errors may lead to effortful processing of new information as members engage in more elaborated discussions aimed at diagnosing the causes of the failure and planning for future scenarios. As Wilson et al. (2007) argue, this elaboration should strengthen the memory record and facilitate the persistence and recall of the knowledge over time.

Retrieval

The final component of group learning is retrieval, which means that groups can locate and access stored knowledge for later use (Wilson et al., 2007). Although retrieval is a necessary condition for group learning to occur, it too has received minimal attention in the literature on group learning. Thus, very little is known about the retrieval process and how it is influenced by features of groups (e.g., social processes, stability of membership) and other contextual factors (e.g., time). Yet, based on what we currently know about the retrieval process in groups, it is likely that errors affect a group's ability to find and access stored knowledge. In particular, errors may affect retrieval through two general mechanisms. First, Wilson et al. (2007) argue that the retrieval of group learning is closely intertwined with the group learning processes discussed above. This suggests that errors may impact retrieval indirectly through their effects on knowledge sharing and storage. For example, knowledge sharing increases the number of group members that are able to recognize and respond to retrieval cues. Thus, by stimulating social exchange and sensemaking in groups, errors may facilitate the subsequent retrieval of new knowledge. In addition, the strength of a stored memory record influences the likelihood the knowledge will be retained and successfully retrieved when needed. As argued above, errors may lead teams to engage in elaborative processing, which may strengthen the knowledge record and allow the team to retrieve the information over time.

In addition to these indirect effects, errors may also directly influence the likelihood that a team will engage in retrieval processes and be able to apply the retrieved knowledge to a new situation. Wilson and colleagues (2007) note that in order for retrieval to occur a group or one of its members must first recognize the need to access stored knowledge. The retrieval mechanism is triggered when features of a stimulus situation cue a particular learning stored in the group's knowledge repository. However, as noted earlier, teams often fail to recognize novelties in their task environment and, as a result, may retrieve outmoded routines (Gersick & Hackman, 1990). In addition, when teams have significant tenure, previous learning and established mental models may inhibit the retrieval of new, updated learning. Errors can serve as important feedback to a team, highlighting misunderstandings or shortcomings that frustrate effective action and triggering the retrieval of new or additional information (Cannon & Edmondson, 2001; Tjosvold et al., 2004). Yet, as Hofmann and Frese (this volume) note, error detection is difficult because the "error signal" is often nested within a flow of feedback characterized by a high degree uncertainty and equivocality. Moreover, an undetected error cannot stimulate learning. Thus, teams should engage in practice activities designed to build a broader repertoire of behaviors and develop greater adaptive capacity (Kozlowski et al., 1999). For example, exploration and trial-and-error experimentation expose teams to a wider range of task material. Although the material may not be relevant to the team's current task, it is valuable knowledge that a team can access and utilize when faced with a novel situation (Bell & Kozlowski, 2009). Finally, when teams diagnose error episodes and plan for future challenges (e.g., self-correction), they also generate retrieval cues they can use to recognize situations in which specific knowledge should be accessed (Kozlowski et al., 1996).

Error Management within Teams

Hofmann and Frese (this volume) argue that there are two primary strategies that can be used to deal with errors. The first is error prevention, where the focus is on reducing the occurrence of errors. The second is error management, where the focus is on disconnecting the error from error consequences. Although most complex organizations focus on preventing errors, there are several limitations to this approach. First, a pure error prevention approach overlooks the fact that errors are ubiquitous and even the most well designed systems can never eradicate all human error, particularly in today’s complex and dynamic organizations (Bauer & Mulder, 2007; Reason, 1990). Second, error prevention reduces the learning potential of errors and ignores the fact that some errors have long-term, positive consequences for individual, team, and organizational effectiveness (Hofmann & Frese, this volume).

However, as Hofmann and Frese note, both error prevention and error management share the common goal of reducing the negative consequences of errors. Thus, they suggest that organizations adopt a dual-pronged approach aimed at preventing error consequences. Specifically, organizations should focus on error prevention to try to prevent errors from occurring but should also add a second layer of defense in the form of error management, which involves intercepting and correcting errors that occur before they produce negative consequences. In the following section we examine the process of error management, focusing attention on the goals of the process and the necessary conditions for error management to be successful. We then consider factors that influence error detection and error management in team contexts. In particular, we examine three categories of factors – team characteristics, team climate, and team interventions – that impact a team's ability to detect, trap, and recover from failure.

The Error Management Process

Kontogiannis (1999) argues that there are three processes in error management. The first is error detection, or realizing that an error is about to occur or suspecting that an error has occurred. He notes that error detection can occur in different stages of performance. First, errors can be detected in the outcome stage, such that a mismatch between expected effects and observed outcomes signals an error. In this case, error detection occurs "after-the-fact," or after the action cycle has concluded. Failures in error detection at this stage often stem from the challenges involved in attending to actual outcomes and remembering expected outcomes. Second, errors can be detected during the execution stage when individuals recognize a mismatch between the actions being executed and the actions specified in their plans. Finally, errors can be detected during the planning stage, such that individuals recognize wrong intentions or mismatches between intentions and formulated plans. Error detection during the execution and planning stages is based on indicators of error that emerge during the action cycle and is influenced by the clarity, or strength, of these error signals (Hofmann & Frese, this volume). After an error has been detected, it is then important to explain why the error occurred. Error explanation represents the second process of error management and it is important for learning from errors, as discussed previously. In addition, error explanation facilitates the final process of error management, error correction, which involves the modification of an existing plan or development of a new one to compensate for the mistake.

The success of error management in reducing the negative consequences of errors is influenced greatly by the timing of error detection and recovery. Hofmann and Frese (this volume) argue that errors that remain after the conclusion of the action cycle are more likely to negatively impact the performance of other entities within the organization. In contrast, errors that are detected during the action cycle can potentially be captured before these negative consequences are realized. The primary objective of error management, therefore, should be to trap errors during the action cycle so as to prevent or minimize their consequences on the system (Helmreich, Wilhelm, Klinect, & Merritt, 2001). It is also important to detect errors quickly, because errors that remain latent in a system can grow and accrue over time, resulting in much more serious long-term consequences (Hofmann & Frese, this volume). In addition, efficient error detection and recovery helps to reduce error cascades that can occur as one error leads to other errors. For example, error management can help reduce the frustration and stress that often accompany errors, thereby preserving cognitive resources required for successful performance and minimizing debilitating motivation losses. Finally, error management contributes to secondary error prevention. As individuals diagnose errors and uncover their potential causes, they are in a better position to prevent the error from occurring in the future (Hofmann & Frese, this volume; Kontogiannis, 1999).

Error management is a difficult and complex process, particularly in team settings. Thomas (2004), for example, examined error management among flight crews and found that nearly half of all errors remained undetected. Further, he found that less than a fourth of all errors were effectively managed by the flight crews. Research suggests there are several necessary conditions for error management to be successful in team environments. One of the most important is that there must be a general expectation that errors will occur. If individuals do not recognize the possibility of errors, then little effort will be put forth to determine if an error has occurred (Hofmann and Frese, this volume). Kontogiannnis (1999) argues that error suspicion and curiosity can overcome complacency and help individuals maintain vigilance for subtle changes in the environment. In teams, individuals must devote attention to monitoring not only their own performance but also that of their teammates. Research suggests that mutual performance monitoring is critical for the reduction of catastrophic errors (Salas, Burke, & Stagl, 2004; Wilson et al., 2005) and team leaders can play an important role in monitoring the progress of a team toward its goals and providing the feedback necessary for error detection and management (Salas, Burke, & Stagl, 2004).

Mutual performance monitoring requires not only the expectation that errors will occur but also the ability to recognize errors in others' performance. Hutchins (1994) argued that for errors to be detected by other persons, the detector must possess sufficient knowledge of the task being performed to be able to determine whether it has been performed correctly and must have knowledge of the possible goals associated with a task. Accordingly, researchers have suggested that error management in teams requires that members possess a shared understanding of the task and team responsibilities. As Salas et al. (2007) state, "Team members must share mental models of the task, team, and equipment in order to be aware of their teammates' surroundings, and to correctly recognize abnormalities in their fellow team members' performance" (p. B81). Shared awareness not only alerts team members to latent errors but also facilitates team coordination efforts to contain and minimize errors that occur (Wilson et al., 2005). One factor that has been shown to contribute to shared awareness is the transparency of organizational and technical systems (Hofmann & Frese, this volume; Kontogiannis, 1999). Transparency allows team members to develop a better conceptualization or mental model of the system. However, research suggests that there are a multitude of factors that can shape the error management process in teams and we explore several of these in the next section.

Factors that Influence Error Management in Teams

Given the importance of error management to team learning and performance, a growing number of studies have focused attention on better understanding the factors that enhance or inhibit a team's capability to successfully detect and correct its mistakes. In this section, we examine three broad categories of factors – team characteristics, team climate, and team interventions – and their influence on error management in team contexts.

Team characteristics. Salas, Burke, and Stagl (2004) note that all teams are not created equal and different types of teams face different challenges to preventing and managing errors. For instance, in commercial aviation, errors are often due to failures in coordination that arise from the fluid nature and short life span of flight crews. In medical teams, error management is often made more difficult by status differences and clear lines of hierarchy that determine who can question others' actions. Rather than focusing on error management in specific types of teams, it is more informative to consider the implications of different team characteristics for error management. Indeed, Kozlowski and Bell (2003) argue that the value of team typology is in understanding the factors that constrain and influence effectiveness for different types of teams. They highlight six features that capture a majority of the unique characteristics that distinguish different team forms. One feature they discuss is team member diversity. As discussed earlier, for team members to recognize the mistakes of others they must possess a shared understanding of task and team responsibilities. It may be more difficult for teams to develop this shared awareness when members are drawn from diverse backgrounds. Rosen et al. (2008), for example, note that one of the barriers to error management in healthcare is the fact that medical teams are comprised of individuals from highly diverse backgrounds in terms of expertise, training, and experience. In a recent study, Van der Vegt and Bunderson (2005) suggest that one of the keys to overcoming the disruptive tendencies of expertise diversity in teams may be collective team identification. They argue that when there is a shared sense of identification with the team, members will be more motivated to interact and exchange information in the face of diversity. Indeed, they find that expertise diversity is negatively related to learning and performance for teams with low collective identification but positively related to learning and performance among teams with high levels of collective identification. However, they also find some evidence that even among teams with high levels of collective identification, very high levels of expertise diversity impede team learning and performance. Nonetheless, teams characterized by a high level of homogeneity face their own challenges to error management due to groupthink and a failure to engage in mutual learning (Wong, 2004). Ultimately, it appears that teams that possess moderate levels of diversity combined with high levels of collective identification may be best equipped to manage and learn from their errors.

A second key feature discussed by Kozlowski and Bell (2003) concerns the performance demands that teams face. Complex teams are characterized by performance demands that require coordinated individual performance in real-time, the ability to adapt to dynamic goals and contingencies, and a capacity for continuous improvement (Kozlowski et al., 1999). In contrast, simple teams are characterized by minimal performance demands that allow for pooled or additive workflow arrangements. Although complex teams may be more susceptible to errors that occur due to a breakdown in teamwork (e.g., coordination/collaboration), the high level of workflow interdependence may facilitate mutual performance monitoring and create redundant systems for trapping errors. However, when performance demands are high, teams may have trouble detecting errors, because in complex action cycles error signals are often unclear (Hofmann & Frese, this volume). Salas, Burke, Fowlkes, & Wilson (2004) suggest that complexity may also moderate the effects of diversity on team performance. In particular, they suggest that cultural diversity may facilitate performance on simple tasks. However, on complex tasks that require significant coordination, cultural diversity may result in teams not performing to their full potential. It will be important for future research to further explore the relationship between team complexity and error management given the need for complex teams to use errors as a source of learning and continuous improvement.

Although having received less attention, researchers have examined several other team characteristics, such as collocation/spatial distribution and temporal characteristics, as potential factors that influence error management. Fletcher and Major (2006), for example, examined differences in error correction across teams utilizing one of three communication modalities: face-to-face, audio, and audio plus a shared workplace application. They did not find any difference in uncorrected errors between the face-to-face and audio only conditions, but they did find teams left more uncorrected errors in the audio only condition than in the shared workspace condition. This finding lends some support to the authors' argument that communication modalities low in information richness may make it more difficult for teams to monitor and correct their errors. Cooke, Gorman, Duran, and Taylor (2007) compared the performance of teams with experience working together in a command-and-control setting to inexperienced teams on an uninhabited aerial vehicle simulation. They found that experienced teams exhibited fewer errors on one of the training segments concerned with coordination, suggesting that individuals familiar with these kinds of coordination situations were able to transfer this teamwork knowledge between tasks. Edmondson, Bohmer, and Pisano (2001) also suggest that team stability can influence team learning. They argue that keeping team members together helps to develop transactive memory systems, which can enhance team learning. However, they also note that stable teams may fall into habitual routines and fail to respond to changing conditions. Overall, the effects of temporal issues, such as team lifecycle, on error management warrant future research attention.

Team climate. In addition to team characteristics, prior research suggests that a team's climate can influence the error management process. Cannon and Edmondson (2001) argue that two capabilities must exist for organizations to learn from their failures: members must be able and willing to take risks and they must be able to acknowledge failure rather than covering it up. The extent to which members engage in these activities is influenced greatly by the climate that exists within the team. Edmondson (1999), for example, argues that team psychological safety, which is defined as "a shared belief that the team is safe for interpersonal risk taking" (p. 354), is important for creating a supportive interpersonal climate in which members can raise concerns or reveal mistakes without it being held against them. Similarly, Burke et al. (2004) argue that in high reliability environments, team members must treat every potential opportunity as a learning event and must be willing to raise concerns. Mutual performance monitoring has little value if team members are afraid to speak up when they notice something out of the ordinary. As Burke et al. (2004, p. i101) state, "The ability to speak up in a non-threatening and respectful manner (deference to expertise) is a hallmark of learning organizations and the teams within them."

Yet, teams often face numerous barriers to creating a climate that supports the process of identifying and learning from failures. Edmondson (2004), for example, discusses how nurses and doctors face extreme pressures on their time, which can limit opportunities to engage in root cause analysis and instead force quick patches to problems. For teams to effectively manage and learn from their mistakes, time must be devoted to reflective activities, such as debriefings (Salas, Klein, et al., 2008). Helmreich et al. (2001) point out that the professional culture in aviation is one in which many pilots have unrealistic perceptions of invulnerability and there is a strong sense of hierarchy, which can prevent crew members from acknowledging their own or others' mistakes.

Although the organizational and professional context in which a team operates can influence how members respond to errors, there exists some evidence that the group context may represent a more powerful influence on members' attitudes and behaviors. Edmondson et al. (2001), for example, studied 16 hospitals implementing a new technology for cardiac surgery. They found that organizational differences, such as resources and senior management support, were not associated with implementation success. Rather, successful implementers engaged in a qualitatively different team learning process than those that were unsuccessful. All of the successful implementers, and only one of the unsuccessful implementers, established a climate in which lower-status team members were comfortable speaking up with observations. Using data from 51 teams in a manufacturing organization, Cannon and Edmondson (2001) showed that beliefs about failure were shared within and varied between groups in the organization. These differences were found despite the fact that all of the teams were embedded in the same organizational context, which emphasized the importance of learning from mistakes. These results suggest that although the organizational context is important, factors in the more proximal team context may have a greater influence on how members view errors and whether they leverage failure as a learning opportunity.

Given the importance of team members' shared beliefs about failure, it is important to understand the antecedents of these climate perceptions. Prior research suggests that leaders are in a position to reframe failure as essential to learning, thereby shaping team members' attitudes toward errors. Cannon and Edmondson (2001), for example, found that leader coaching (e.g., initiation of discussions around improvement) encouraged team members to adopt productive attitudes and behaviors about failure. Edmondson (1996) found that detected unit error rates were strongly and positively associated with high scores on nurse manager direction setting and coaching, which suggests that certain leaders establish a climate of openness that facilitates the reporting and discussion of errors. In addition to shaping learning-oriented beliefs in teams, leaders need to coach subordinates on how to constructively discuss failure and also need to set a clear direction for the team so members can recognize deviations when they occur (Cannon & Edmondson, 2001). Although a collective orientation towards learning often promotes higher levels of team performance, recent research by Bunderson and Sutcliffe (2003) suggests that an emphasis on learning may compromise performance when teams are already performing at a high level. Their results suggest that leaders may only want to encourage active experimentation and risk taking when established activity patterns have proved ineffective.

Team interventions. A third and final category of factors that can influence error management in teams involves human resource management interventions specifically designed to enhance members' capacity to identify and rectify deficiencies in individual and team performance. Although observers have noted that the traditional HR system is ill-equipped to support and sustain team-based work units, research has examined the efficacy of several different HR practices for helping teams manage their errors. Much of this work has focused on various training strategies that can be used to develop high reliability teams. For example, simulation-based training can allow teams to practice trapping and recovering from errors and can provide feedback that is useful for preventing future errors (Salas, Cooke et al., 2008). In addition, self-correction training has been used to help teams correct unsafe behaviors and avoid them in the future, and perceptual control training can facilitate cognitive skills, such as noticing, performance monitoring, and situational awareness, that can aid teams in error identification (Wilson et al., 2005). For a more detailed discussion of the role of training and development in facilitating error management in teams the reader is directed to the chapter by Salas and colleagues in this volume.

A large body of research has also examined the role of technology and automation in helping teams to manage and avoid errors. Research evidence is mixed with respect to how automation influences error management in teams. Wright and Kaber (2005), for example, reviewed four different types of automation and concluded that certain types, such as automation of information acquisition, enhance teamwork skills and team effectiveness, while other types, such as decision automation, can compromise team performance. Further, the effects of automation can differ depending on task difficulty. For example, decision automation has been found to have negative effects on team effectiveness at high levels of task difficulty, but positive effects under conditions of low task difficulty (Wright & Kaber, 2005). These results may be explained by the fact that technology does not always ease teamwork demands, and in fact can often increase them. For example, Webster and Cao (2006) found that more verbal exchanges were required when surgical teams moved from conventional laparoscopy to a robotic system. In addition, the use of automation to reduce specific types of errors can be accompanied by increases in other types of errors. For example, the availability of automated decision aids can lead decision makers to use these aids as a replacement for vigilant information seeking and processing, a phenomenon known as automation bias (Mosier, Skitka, Dunbar, & McDonnell, 2001). Automation bias can result in a failure to respond to system irregularities when not prompted to do so by an automated device (omission error) and to inappropriately following an automated recommendation without verifying it against other available information or despite contradictory information (commission error). In summary, automation may aid teams in avoiding errors, but such systems should not be viewed as a substitute for active error management in teams.

Future Research Directions

The goal of this chapter was to advance theory and research on collective failure by focusing on the emergence, consequences, and management of errors in teams. Early on, we recognized that this would be a challenging endeavor given the paucity of research on errors in teams. Although the literature on team effectiveness has grown dramatically in recent decades, relatively little of this work has focused on errors specifically and on their implications for team learning and performance (Tjosvold et al., 2004). The more extensive literature on human error and its effects on individual learning and performance provides valuable insight into the potential effects of errors in team contexts, but one also needs to exercise caution in generalizing findings across levels of analysis. Accordingly, we conclude the chapter with a discussion of several important gaps in research on errors in teams and highlight potential directions for future work in this area.

Understanding the emergence of errors in teams. As we have discussed, errors in teams can occur at the individual, dyadic, or collective level, and the level at which an error originates may have important implications for how it propagates within a team to influence performance. However, team errors have often been studied by examining failures in team performance, which provides limited information about the root cause of an error. Salas, Cooke et al. (2008), for example, suggest that in team environments it is important to distinguish between errors that arise during taskwork processes and those that occur during teamwork processes. Both types of errors may undermine team performance, but errors in taskwork processes suggest deficiencies in individual capacity and performance, whereas errors in teamwork processes point to problems surrounding team capacity, processes, and performance. Thus, information about the origin of different types of errors in teams is valuable for guiding root cause analyses and developing effective error management strategies. It will also be important for future research to study the emergence of errors within teams over time. For example, whether an error emerges early or late in a team's performance cycle and the length of time an error remains latent in a system can influence the chances of a team successfully trapping the consequences of the error (Hofmann & Frese, this volume). Also, whether an error reoccurs in future performance episodes is an important indicator of whether a team has successfully learned from its mistakes. Cross-sectional studies can only provide a limited understanding of the nature of errors in teams and the effectiveness of error management processes.

Mapping the effects of errors on team learning processes. Prior work has provided convincing evidence that detected errors represent an important stimulus of team learning. Teams that openly reveal, discuss, and reflect upon their mistakes expand their repertoire of potential behaviors and exhibit performance improvement over time. What is less clear, however, is how errors facilitate and shape the *process* of group learning. As Kozlowski and Ilgen (2006) note, team learning has rarely been assessed directly as a construct and instead has been inferred from changes in team performance. Further, prior research has focused significant attention on particular group learning processes, such as knowledge sharing, but has neglected others, such as knowledge storage and retrieval (Wilson et al., 2007). The result is that we possess only a limited understanding of the processes involved in team learning, which makes it difficult to speculate about how errors may influence these processes. In addition, very little work has examined how errors that occur *during* these processes impact team learning and performance. Thus, it will be important for future research to focus attention on mapping the effects of errors onto critical team learning processes. We believe that the model of group learning specified by Wilson et al. (2007) may prove useful in such efforts, as it provides an account of the information-processing activities that should take place for a group to learn (c.f., Kozlowski and Bell, 2008). In this chapter, we have discussed how errors may influence these processes of group learning, but future research is needed to empirically test our propositions.

Identifying the factors that influence error management in teams. Errors within teams are unavoidable. However, whether an error results in learning and performance improvement or has a detrimental effect on team performance will depend largely on how well the team manages the error. Recent research has provided significant insight into the error management process and the challenges that surround error detection and recovery (Hofmann & Frese, this volume; Kontogiannis, 1999). We know that teams often struggle to manage their errors, resulting in a large proportion of errors remaining either undetected or uncorrected (e.g., Thomas, 2004). However, our ability to reverse this trend is hampered by the fact that we currently possess a limited understanding of the factors that enhance and inhibit error management in team contexts. For example, prior work has established team member diversity as having an important influence on error management, but the impact of other team characteristics, such as team lifecycle, on error management have rarely been examined. This may be due, at least in part, to the fact that the vast majority of research that has examined errors in teams has been conducted in healthcare, aviation, and military settings. This is not surprising when one considers that teams perform much of the work in these settings and errors in these contexts often have dire consequences. Yet, medical teams (e.g., nursing units, surgical teams), flight crews, and combat teams are all examples of action teams, characterized by members who possess specialized expertise, a high degree of integration with other work units, and work cycles that involve brief, repeated performance events (Sundstrom, De Meuse, & Futtrell, 1990). The overrepresentation of action teams in this literature limits our understanding of the implications of errors for other types of teams, such as product and service, project, and top-management teams. More importantly, it makes it difficult to determine how different team characteristics, such as workflow interdependence and boundary permeability, may influence error management. For example, project teams require little external synchronization, which may provide greater opportunity for them to trap errors before they impact other entities within the organization. Moving forward, it will be important for research in this area to focus on a wider variety of team types so as to better understand how the features that distinguish among different team forms influence the process of error management.

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Figure 1: The Moderating Influence of Task Interdependence on the Relationship between Individual and Team Error