Teams, Teamwork, and Team Effectiveness: Implications for Human Systems Integration

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Teams, Teamwork, and Team Effectiveness: Implications for Human Systems Integration

The last two decades have witnessed a worldwide reorganization of work from individual jobs in a functional structure to work structured around teams and the technologies that link team members together in a workflow system (Kozlowski & Ilgen, 2006). Indeed, the workflows for mission-critical problems often transcend single teams, systems, and organizations. Imagine the following scenario. A person has been involved in an automobile accident after the driver made an error, lost control of the vehicle, and hit a tree head on. Immediately, an automated system within the vehicle detects the crash and contacts a command and control (C^2) team that alerts authorities. Several teams are immediately dispatched to the scene of the accident. A team of police officers reroutes traffic away from the site. A firefighting team extracts the person from the wreckage, suppresses the potential for fire, and contains potential contaminants. Emergency medical technicians perform stabilization and rush the patient to a hospital trauma unit. In transit, they alert the hospital and transmit the patient's vital signs and injury assessment. On arrival, an emergency medical team stabilizes the patient, who is then transferred to the Intensive Care Unit for further attention by multiple medical teams who coordinate ongoing care.

This example illustrates several critical points about teamwork and HSI. First, team members and their expertise are integrated with the tasks, roles, and technology systems that comprise their mission and its goals. To perform effectively, team members have to coordinate their collective cognition, affect/motivation, and behavior (Salas, Cooke, & Rosen, 2008). Effective HSI will enhance coordination and teamwork. Lack of attention to teamwork as an integral aspect of HSI will inhibit teamwork, forcing team members to improvise to overcome technology and system limitations. Second, teams bring together a range of distinctive expertise, allow rapid deployment, and are adaptable. Although good HSI can make them robust to errors, poor design can yield a workflow system that propagates an error and allows it to cascade through the system (e.g., USS Vicennes; Bell & Kozlowski, 2011). Finally, forms of teamwork and technology systems often transcend team and organizational boundaries. Many critical missions, as in our example, involve multiple teams (i.e., multi-team systems, MTS; Mathieu, Marks, & Zaccaro, 2001), team networks (Wax, DeChurch, Murase, & Contractor, 2012), or systems of systems (Pew & Mavor, 2007) that cut across organizational boundaries working collaboratively and cooperatively to accomplish the overall mission of "saving the patient," "ensuring a safe flight," or "monitoring cyber security."

Understanding the "human" in human systems integration (HSI) necessitates an understanding of this interplay of the person, team, technology, and system (Durso, Boehm-Davis, & Lee, this volume). The goal of this chapter is to provide an overview of the key considerations for HSI relevant to teams, teamwork, and team effectiveness. Given space constraints, we focus on achieving breadth of coverage and identifying core concerns, with pointers to more in depth coverage of relevant topics that are beyond the scope of the chapter. The chapter is structured as follows. We first characterize work teams and identify core considerations for team effectiveness and, thus, HSI. Then, we highlight research findings on team effectiveness organized around the input-process-output heuristic (IPO; McGrath, 1964) and its more contemporary dynamic representations. Finally, we close with a consideration of critical theory development and research issues necessary for advancing HSI with respect to supporting and enhancing team effectiveness.

Core Team Effectiveness Considerations for HSI

Work teams and HSI. Integrating several perspectives, Kozlowski and Ilgen (2006, p. 79) define teams as "(a) two or more individuals;[1] (b) who interact socially (often face-to-face or, increasingly, virtually); (c) possess one or more common goals; (d) are brought together to perform organizationally relevant tasks; (e) exhibit interdependencies with respect to workflow, goals, and outcomes; (f) have different roles and responsibilities; (g) and are together embedded in an encompassing organizational system, with boundaries and linkages to the broader context and task environment."

The incorporation of teams and teamwork into technology systems creates a variety of challenges for the human-oriented analytics typically used by HSI (e.g., Folds, this volume). The HSI practitioner should be aware and knowledgeable of these potential challenges to inform system design specifications that better incorporate teamwork considerations and to develop appropriate evaluation strategies that incorporate the multilevel character of team processes and effectiveness. As Folds (this volume, p. 22) states, "…*design* is at the heart of the systems engineering process, and consequently is where HSI has the potential to make the biggest contribution. Design involves actively composing (conceiving of, and describing) some configuration of hardware, software, and people

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[1] Dyads can be distinguished from teams comprised of 3 or more people. Two-person teams (e.g., aircrews) often exhibit the same basic work processes as larger teams, although we acknowledge that teams of three or more enable coalitions and related interpersonal interaction complexities absent in dyads.

(and procedures or other attributes) to create functionality that provides desired performance capability of some system." Core issues center on the multilevel character of teams, workflow interdependence, virtuality, artificiality, MTSs and networks, and the dynamics of team processes and adaptation.

Multilevel character. Teams implicate multiple levels of analysis and this multilevel character naturally encompasses human-technology systems. Lower levels of such systems are "nested" (i.e., included, bound, and constrained) by progressively higher system levels. Two fundamental systems processes shape multilevel phenomena relevant to team effectiveness (Kozlowski & Klein, 2000). First, top-down *contextual effects* shape and constrain lower-level processes and constructs (e.g., environmental complexity shapes the team workflow structure). Second, bottom-up *emergent processes* at the lower-level coalesce and manifest at the team level. In that sense, teams, team processes, and team effectiveness are at the juncture of micro, lower-level individual properties that emerge as team level phenomena and macro, higher-level organizational and technology system characteristics that shape emergence.

The multilevel character of technology systems, teams, and team effectiveness is a challenge for HSI because most design and analysis tools (i.e., job, task, and cognitive analysis; selection; training) focus on the individual level of analysis. Emergent phenomena – the interplay between individual cognition, motivation, and behavior and team processes – are not always simply additive as such tools implicitly assume. An understanding of how the technology system shapes team interactions and the process mechanisms of emergence (Kozlowski, Chao, Grand, Braun, & Kuljanin, 2013) is critical for HSI. In this regard, the key focus is on the workflow interdependence that is inherent in the way that the technology system links team members to one another and the team task.

Workflow interdependence. Structural interdependencies among team members are driven and constrained by the design of a technology system. Tasks are clustered into distinct roles within the system that are aligned with the expertise of team members. Increasingly, roles may be accomplished by automated entities (e.g., robot, UAV) that have some degree of autonomy (Cuevas, Fiore, Caldwell, & Strater, 2007). The workflow interdependence structure is aligned with the complexity of the team task and, together, determines the nature of coordination demands (i.e., exchanges of information and/or behavior) placed on team members (Bell & Kozlowski, 2002; Van de Ven, Delbecq, & Koenig, 1978)[2]. At the simpler end of the complexity continuum, pooled structures are additive such that team members essentially perform in parallel. Emergence is additive in nature with the potential for compensation (i.e., weak performance of one member can be compensated by strong performance among other members). Sequential structures are a series of input-output transactions that minimize coordination at each exchange. Emergence is additive but conjunctive (i.e., the weakest link determines team performance). Both structures entail weak, asynchronous internal linkages, relatively weak external coupling, and are most appropriate in relatively stable and predictable environments. Toward the more complex end of the continuum, reciprocal structures entail more flexible patterns of coordination. Reciprocal structures enable feedback and adjustment at input-output transitions and allow greater reach-back. Intensive structures represent the most flexible and adaptive coordination mechanisms (Kozlowski, Gully, Nason, & Smith, 1999). Emergence is represented by configurations, patterns, or networks. Both structures entail stronger and more synchronous internal linkages, tighter external coupling, and are more appropriate for dynamic and adaptive contexts. Supporting team member coordination and adaptation under more complex workflow structures represents a significant challenge for HSI. As we will discuss, system mechanisms to facilitate team cognition, maintain team motivation, and regulate team action are essential.

Virtuality. Most of the research foundation on team effectiveness is focused on face-to-face teams; however, with ever advancing communication and computer technologies, work teams are becoming increasingly virtual, spread across time and space. Virtuality is typically treated as a composite of geographic distance and characteristics of electronic communication / data media (e.g., Bell & Kozlowski, 2002; Kirkman & Mathieu, 2005; Mesmer-Magnus, DeChurch, Jimenez-Rodriguez, Wildman, & Shuffler, 2011). In addition, as virtual teams become increasingly global, there is an additional emphasis on cultural differences that make it challenging for team members to communicate and build shared understandings (Hinds, Liu, & Lyon, 2011). Some degree of virtuality is increasingly the norm—even for teams that are essentially co-located—and a primary feature of most technology mediated workflow systems; as such, it represents a critical HSI consideration for team effectiveness.[3] System mechanisms are required to build shared understanding and coordinated action.

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[2] Steiner (1972) and McGrath (1984), among others, provide alternative team task taxonomies.
[3] See Kirkman, Gibson, & Kim (2012) for a comprehensive review.

Artificiality. The increasing sophistication of artificial intelligence is yielding a new form of teammate: a synthetic autonomous entity that functions as an integral part of the team (Cuevas et al., 2007). Such entities may range from remote vehicles or robots under essentially continuous manual control to sophisticated unmanned vehicles that can perform a mission with minimal supervision. The challenge for HSI is that the actions of such entities need to be appropriately calibrated to the team and system. Entities that require continuous monitoring are likely to exacerbate errors and inefficiencies rather than reducing them. However, entities that operate with considerable autonomy can also be problematic if they are not contextually sensitive to team pacing, synchronicity, and goal states. The challenge is to design entities or system capabilities that help artificial teammates *coordinate with humans* rather than creating fully autonomous agents that add cognitive load and uncertainty for their human counterparts.

Multiteam systems and networks. MTS and networked systems (e.g., Contractor, Wasserman, & Faust, 2006) are another emergent form of teamwork that have implications for HSI. Mathieu et al. (2001, p. 290) define MTSs as "two or more teams that interface directly and interdependently in response to environmental contingencies toward the accomplishment of collective goals. MTS boundaries are defined by virtue of the fact that all teams within the system, while pursuing different proximal goals, share at least one common distal goal; and in doing so exhibit input, process, and outcome interdependence with at least one other team in the system." Elaborating on this conceptualization from a network theory perspective, Wax et al. (2012) describe MTSs as "a specific type of social network, one where every network member is interdependent in some way towards the accomplishment of a network-level purpose." Our opening example focused on a type of MTS. Other exemplars include the air traffic control system (i.e., ground controllers, flight controllers, sectors, aircrews) and military C^2 systems.

This conceptualization of MTSs, team networks, and systems of systems is consistent with the nature of large integrated "systems" that comprise HSI. Thus, the challenge for system designers is to anticipate the needs of face-to-face proximal teams, virtual teams, and extended MTS networks. For example, component systems are often designed with little regard to the operation of the overall MTS. Different component systems may have different communication protocols, data standards, and display functions. (e.g., submarine underwater navigation requires integration of data streams from different component systems that is largely accomplished manually). Suboptimal design can be a critical source for system inefficiencies and even catastrophic errors (e.g., Three Mile Island, USS Vinceness). MTSs thus raise implications for system definition, boundaries, and levels that need to be encompassed by HSI.

Dynamics and adaptation. Finally, teams are not static entities, although much of the empirical research treats them as such. Team tasks are often cyclic and episodic such that the cognitive and behavioral workload on team members is variable; dynamics have implications for a variety of team functions, including leadership (Guastello, 2010a; Kozlowski, Gully, McHugh, Salas, & Cannon-Bowers, 1996) and activity pacing (Marks, Mathieu, & Zaccaro, 2001). Teams also evidence developmental progression; they evolve over time, become more proficient with experience and, with appropriate training and interventions (Gorman, Amazeen, & Cooke, 2010a; Gorman, Cooke, & Amazeen, 2010b), can develop adaptive capabilities (Kozlowski et al., 1999). Thus, the "human" in HSI is not fixed. Individuals, teams, and the systems in which they are integrated vary dynamically as the performance environment evolves (see Baard, Rench, & Kozlowski, 2014, for a comprehensive review; Guastello, 2010b). This means that an important part of system design and operation is to build in features that can monitor team processes (e.g., communication, collaboration, coordination) and intervene to maintain team effectiveness (Gorman, Hessler, Amazeen, Cooke, & Shope, 2012; Kozlowski & Chao, 2012b). Facilitating and supporting these changing components mark another key HSI challenge.

The Science of Team Effectiveness

HSI practitioners contribute to technology systems at a variety of stages, including requirement development, initial design, acquisition, evaluation, and refinement. Nevertheless, a critical axiom of effective HSI is "sooner is better than later" (Folds, this volume). Consequently, the purpose of the following sections is to highlight key findings from team effectiveness science such that HSI efforts involving teams can accommodate the unique demands, requirements, and processes inherent in these contexts throughout the entirety of a system's development.

McGrath's (1964) influential IPO framework serves as a useful organization of factors that contribute to team effectiveness. *Inputs* are characteristics of the individual (e.g., knowledge, skills, and abilities [KSAs], demographics), the team (e.g., size, power structure), and the environment (e.g., external stressors, reward conditions) that enhance or constrain a team's processes. *Processes* are cognition-, affect-/motivation-, and behavior-based phenomena (e.g., developing transactive memory, cohesion-building, collaborative problem-solving) that emerge from group member's task interactions and influence the favorability of team outcomes. *Outcomes* reflect the cumulative results of team's efforts; these may be performance-related (e.g., quantity and quality of a product), ability-related (increases in relevant abilities and skills), or affect-related (member satisfaction, commitment to team and teammates).

Despite the utility of the IPO framework, contemporary conceptualizations recognize that teams are dynamic, developing and adapting over time as members collaborate to complete tasks (e.g., Ilgen, Hollenbeck, Johnson, & Jundt, 2005; Kozlowski et al., 1999). Team members bring important contributions to the team (inputs); through their interactions, they develop emergent mechanisms and characteristics (processes) that define them as a collective and help accomplish task goals (outcomes), which subsequently influence future inputs and interactions. As a result, IPO progression—and team functioning—is better construed as a cyclical, dynamic system rather than a linear sequence. Nevertheless, the IPO heuristic is a useful organizing structure.

Team Inputs

HSI implications drawn from the literature on team inputs are most commonly directed towards team selection/staffing (e.g., selecting the right team members to fit a given context, Hollenbeck, DeRue, & Guzzo, 2004). However, an equally important application concerns the design of systems or environments for existing teams or teams in which member capabilities and task expectations are relatively well-defined (e.g., constructing the right system to fit a given or expected set of team members). That is, while staffing represents one pathway through which team inputs can be leveraged to influence team effectiveness, efforts to shape internal and external task environments by proactively anticipating and implementing features, mechanisms, or support tools to facilitate team functioning is a complementary approach.

Team Composition. *Team composition* involves consideration of "who" a team-based system will accommodate. In any HSI effort, decisions relevant to both engineering (e.g., hardware/software design) and manpower (e.g., personnel selection, training) require careful recognition of the KSAs that individuals require to execute tasks and accomplish goals within the system. In team contexts, the KSAs that contribute to task performance are distributed across members; consequently, the manner by which expertise, skills, and capabilities vary within a team should be addressed. As Cannon-Bowers and Salas (1998) note, simply creating a team of high ability experts does not guarantee one will create an effective expert team.

As one example of HSI considerations regarding team composition, consider a system in which team members are expected to perform similar tasks/roles such that aggregate efforts supplement one another (i.e., a team of firefighters that puts out a residential fire by each taking responsibility for a different area of the building) versus one in which members will possess unique roles and responsibilities and individual efforts are complementary (i.e., a team of firefighters in which members allocate specialized responsibilities for putting out a fire, search and rescue, securing area, etc.). These two teams—and, by extension, the composition of their unit members—place different demands on a system's infrastructure. In the former case, HSI manpower acquisition strategies that minimize variance in team member competencies by composing teams with maximal task- and team-relevant KSAs may be beneficial (e.g., Stevens & Campion, 1994); in the latter case, however, team composition that is more specialized to specific team responsibilities is likely to be more efficient and effective (e.g., Ellis, Bell, Ployhart, Hollenbeck & Ilgen, 2005; Cooke, Kiekel, Salas, Stout, Bowers & Cannon-Bowers, 2003). Mathieu, Tannebaum, Donsbach, and Alliger (2014) provide an extensive review and framework for considering how these and other models of team composition have the potential to impact important decisions relevant to system design and evaluation.

Team design. Whereas team composition focuses primarily on the characteristic qualities that "humans in the system" bring with them, issues of *team design* focus on the systemic development, alteration, and regulation of team roles, responsibilities, requirements, and resources that influence how groups and members go about completing task-relevant goals and activities (Levchuk, Levchuk, Luo, Pattipati, & Kleinman, 2002). Many foundational concepts in team design stem from the large body of work on *sociotechnical systems* (STS; Trist & Bamforth, 1951). STS advocates a "joint optimization" strategy in which both social and technical factors must be taken into consideration to successfully design and maintain an effective work group. Of most relevance to HSI practitioners, Trist and Bamforth (1951) suggest that the degree of autonomy given to teams in a system, the extent to which teams are equipped to adapt to unexpected occurrences in their environment, and the meaningfulness of the work teams are given to perform are the most critical factors for regulating performance within STSs.

More recent approaches to team design have focused specifically on how best to organize teams to facilitate task accomplishment. For example, empirical research related to structural contingency theory (Pennings, 1992) suggests that t teams operating in relatively stable task environments are more effective when members are organized functionally (individuals possess limited, highly specialized roles that complement one another) rather than divisionally (team members possess broad, multifaceted roles that enable members to work independently); however, when teams operate in more dynamic environments, divisional structures are superior (Hollenbeck et al., 2002). Alternatively, Humphrey, Morgeson, and Mannor (2009) propose, and evidence supports the notion that teams are most effective when designed to support *strategic core roles,* or the subset of task roles on the team that encounter more of the team's task-relevant problems, have greater exposure to/involvement in the group's tasks, and are more central to the workflow of the team. Consequently, these findings suggest that a critical consideration for effective HSI is the manner by which task demands and team roles are aligned with respect to the goals, needs, and available resources of the system; not all team structures are equally effective across all situations, nor do all individuals equally contribute to a team task (Stewart, 2006).

Team Processes and Emergent States

Team processes colloquially reflect the notion of "teamwork." More specifically, team processes characterize interactions among team members that direct available resources, KSAs, and efforts to resolve task demands. Over time, these interactions produce distinctive structures within a team that shape the development and interplay of subsequent dealings among group members. Such structural team-level constructs are commonly labeled *emergent states* (Marks et al., 2001). For an HSI practitioner, recognizing and anticipating the processes and emergent states relevant to the team(s) for which a task, system, or tool is constructed can provide insight into biases, bottlenecks, or other concerns that could potentially be alleviated through design or training activities. Table 1 summarizes a number of cognitive, affective / motivational, and behavioral processes and emergent states relevant to HSI for effective team functioning.

Cognitive team processes and states. A critical process carried out in virtually all work groups and teams is information processing; members attend to information and events in the environment, evaluate their meaning, store these interpretations, and retrieve/make use of relevant artifacts of this knowledge for task completion (Hinsz, Tindale, & Vollrath, 1997). Meta-analytic evidence indicates that team cognition is related to enhanced team functioning and performance (DeChurch & Mesmer-Magnus, 2010). A variety of team processes comprise overall team cognition, including situational awareness, shared mental models, transactive memory, and macrocognition (Table 2; see Bell, Kozlowski, & Blawath, 2012, for further review). Each of these concepts carries implications for understanding how teams develop and use cognitive resources. With respect to HSI applications though, the literature on team cognition suggests that it is important for practitioners to consider the degree to which the information inputs a team will be utilizing during task performance are *specialized*, *distributed*, and how members are likely to *combine* their information together to produce outcomes.

When information sources in a task are specialized and require expertise to acquire and interpret, the value/importance of each individual team member increases. That is, if a person who is responsible for monitoring and communicating a particular information source to others is called away, becomes overloaded, or is otherwise unable to contribute to the team, the team may suffer because other members are not capable of (or less proficient at) compensating for this loss. Alternatively, in contexts where team members are more "exchangeable" because information demands or members' expertise are less specialized, other individuals can potentially absorb such losses. Consequently, inefficiencies or errors associated with information specialization can potentially be alleviated through a combination of training efforts (e.g., cross-training, Marks, Sabella, Burke, & Zaccaro, 2002) and engineering design choices (e.g., common language/interface for integrating member inputs across multiple roles, McComb, Kennedy, Perryman, Warner, & Letsky, 2010) that improves member exchangeability.

Information distribution, which reflects the extent to which information sources are shared/accessible versus unique/centralized across team members, also impacts team cognition (Mesmer-Magnus & DeChurch, 2009). While increased information distribution within a system allows a team to potentially cover and specialize in more tasks, it places greater demands on the quality of information sharing within the team. However, requiring every team member to monitor or interpret all sources of information can be overwhelming and may encourage suboptimal mental models and information processing. Consequently, the HSI practitioner must be aware of such tradeoffs and take steps during early design and training phases to alleviate potential inefficiencies. In highly distributed environments, for example, technologies that facilitate the creation of cognitive "artifacts" that can be easily stored and retrieved (Fiore, Rosen, Smith-Jentsch, Salas, Letsky & Warner, 2010) can potentially improve information sharing. In less distributed environments, resources that automate certain information processing/sharing activities (e.g., incorporating computer agents to monitor certain information sources, Cuevas et al., 2007) also have the potential to enhance team cognition.

Finally, it is important to reiterate the implications that workflow interdependence and the nature of a team's task hold for team cognition. Task/role synchronicity and the manner by which members combine information to make decisions and take action should be carefully analyzed and accounted for in HSI efforts. For example, Steiner's (1972) task typology offers one useful framework for delineating how groups integrate physical and cognitive resources to accomplish tasks based on conditions of the performance environment. Efforts to classify the task and information needs of a team is particularly useful during early system design stages as it enables the HSI practitioner to anticipate potential areas of cognitive process loss that could be addressed through alternative workflows or task contingencies.

Affective/motivational team processes and states. Although affective/motivational processes are "fuzzier" concepts that exist beyond the team-technical system, team cohesion, collective efficacy, and intragroup conflict are nevertheless important (see Table 1). Primary HIS implications for team affective/motivational processes lie in the design and implementation of system features that enable members to establish, monitor, and regulate action related to individual and team goals (DeShon, Kozlowski, Schmidt, Milner, & Wiechmann, 2004).

Given their multilevel nature, goals in a team task context exist at different system levels; individuals have goals necessitated by their task roles, teams have goals directed by higher-level organizations/systems, and organizations/systems have goals dictated by environmental demands or needs (Chen, Kanfer, DeShon, Mathieu, & Kozlowski, 2009). For the HSI practitioner, understanding these goals and how they relate to one another is important for ensuring that individual and team effort is aligned. DeShon et al. (2004) demonstrate that feedback on personal *and* team goals allows team members to regulate effort and cognitive resources to accomplish goals at *both* system levels more effectively. It also benefits other desirable affective states such as cohesion and collective efficacy, which is likely to reduce intragroup conflict and enhance team performance (e.g., Beal, Cohen, Burke, & McLendon, 2003; de Wit, Greer, & Jehn, 2012).

Thus, practitioners can facilitate HSI in team contexts by informing the design of feedback mechanisms (both in terms of hardware/sensory outputs as well as regular opportunities for developmental feedback during training, from supervisors, etc.) that provide members with information on both individual- and team-level goal progress[4]. Doing so requires careful consideration during job, task, and environment analyses to ensure that important performance criteria across multiple system levels have been identified and are understood. Of additional importance, HSI practitioners are often in the best position to communicate this information to engineering design teams whose task is to create the hardware/software that allows individuals and teams to meet these varying objectives (see Folds, this volume). Fully explicating the needs and purpose of feedback systems to engineering design teams has the potential to not only improve the utility a of hardware/software that carry out these functions, but also allows design efforts to develop in parallel with the goals of stakeholders at multiple levels in the system.

Behavioral team processes and states. Behavioral team processes constitute what teams "do" to produce team performance outcomes, such as communicate, coordinate, cooperate, collaborate, and adapt (see Table 1). A variety of taxonomies have been developed in an effort to categorize behavioral processes into fundamental dimensions of team performance functions (see Rousseau, Aubé, & Savoie, 2006, for a comprehensive review). From the standpoint of HSI, recognition of team behavioral processes is important both for normatively describing how members interact with one another as well as prescriptively identifying patterns of behavior or system capabilities that enable teams to effectively work together. For example, team training strategies such as crew resource management (Kanki, Helmreich, & Anca, 2010) and guided team self-correction (Smith-Jentsch, Zeisig, Acton, & McPherson, 1998) are designed to teach effective behavioral strategies to team members. Meta-analytic evidence strongly supports the efficacy of such team training efforts for improving not only behavioral team processes, but also cognitive and affective processes as well as team performance (Salas, Nichols, & Driskell, 2007).

An added benefit of improving behavioral team processes through resources or training is that it equips teams to more readily adapt to changing demands in the environment (Baard et al., 2014). A critical task of HSI design is identifying potential conditions, processes, and outcomes under which an individual, team, or piece of

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[4] See Kozlowski, Toney, Mullins, Weissbein, Brown, & Bell (2001) for a review and recommendations on the design of performance feedback systems.

equipment may operate; however, no HSI practitioner can anticipate all contingencies. Consequently, it falls to the individuals/users in these contexts to evolve their behaviors to effectively achieve task outcomes. Teams can be beneficial in contexts that necessitate adaptation as teams typically have more “manpower” at their disposal. However, groups must possess both the equipment and expertise that enable rapid communication, high situational awareness, and the ability to coordinate multiple members’ efforts simultaneously. The use of simulation-based training that simulates real-world conditions in controlled environments has been identified as a critical approach for promoting adaptive expertise in both individuals and teams (Grand & Kozlowski, 2013).

Team Outcomes

Hackman’s (1987) tripartite definition of team effectiveness emphasizes (1) performance (evaluations of the effectiveness of members’ observable goal-directed team behaviors and/or products); (2) satisfaction (collective feeling that members’ needs are being met); and (3) viability (willingness of members to remain in the team) as the most critical team outcomes of interest. This definition is intentionally broad. Given that group accomplishment is often the most practically important and salient indicator of team effectiveness, the present review focuses only on team performance outcomes. In the sections which follow, we return to two issues introduced in the opening sections of this chapter that are central to conceptualizing and measuring team performance in HSI: (1) the emergent nature of team behavior and performance and (2) the implications of workflow and task interdependencies for capturing team performance.

Multilevel emergence. Teams are embedded in organizations and technology systems, and individuals are embedded in teams. Hence, team performance is a function of both top-down contextual, as well as bottom-up emergent influences. In team contexts, individual team members hold task knowledge, exert effort, and perform behaviors, but team performance is the output of the team as a collective entity. More generally then, team performance is a higher, group-level construct, though the activities which give rise to this outcome originate from the lower, individual level of analysis (Kozlowski & Klein, 2000). Thus, a crucial step in representing—and subsequently influencing—team performance is capturing how individual members’ actions combine to constitute team level performance.

To bridge the gap between the origin and manifestation of multilevel constructs, Kozlowski and Klein (2000) indicate that higher-level constructs are represented along a continuum of emergence ranging from pure *composition* (higher-level outputs emerge from homogenous lower-level inputs) to pure *compilation* (higher-level outputs emerge from heterogeneous lower-level inputs). Composition constructs are isomorphic such that constituent lower-level and resultant higher-level constructs have the same substantive meaning; the higher-level constructs are therefore a simple, summative combination of the lower-level behaviors (e.g., the number of targets processed by all individuals added together to determine team performance, cumulative number of errors made by team members equals team efficiency, etc.).

Whereas composition constructs stem from convergence or consensus among team members, compilation constructs represent patterns or configurations of lower-level characteristics that collectively yield a meaningful higher-level characteristic similar in function, but not necessarily form, to its constituent elements (Kozlowski & Klein, 2000). That is, the type and amount of contributions made by team members to a task, perception, belief, etc. can vary—and it is this unique distribution of individual-level contributions that reflects the overall team-level construct. For example, team performance in many decision-making contexts with distributed expertise requires different team members to coordinate the completion of specialized, interdependent, and temporally entrained task goals. Team performance in this case is therefore not a straightforward aggregation of each member's contribution, but rather the distribution, variance, or profile of individual-level performance outcomes.

Whether team task performance follows a composition versus compilation pattern of emergence carries significant implications for HSI. When performance is more composition-like, system design and integration should facilitate consensus-building, promote convergence of member's goals, and unite diverse efforts in collectively shared directions. For more compilation-like performance, interventions need to facilitate members' ability to complete their own unique task goals while simultaneously providing capabilities that help individuals effectively coordinate member's disparate actions, KSAs, and task accomplishments.

Workflow design considerations. In addition to understanding the emergent properties of team performance, considerations of a team's workflow structure are also important for evaluating how individuals' cognitions, motivations, and behaviors are translated into team performance. In *pooled* tasks, task roles and responsibilities are divided among team members in such a way that linear combinations (i.e., frequencies, means, sums) of individual behaviors are appropriate for capturing team-level phenomenon (Kozlowski & Klein, 2000). Aggregating individual performance to the team level in pooled tasks is thus relatively straightforward as emphasis is placed on high uniformity and low dispersion of member performance-related activities. As a result, compositional, additive aggregation for forming team performance composites are prevalent in the HSI and team effectiveness literatures (e.g., Brannick, Prince, & Salas, 1995). This aggregation method is appropriate for tasks with pooled workflow structures and compositional team performance; however, more complex workflows with compilational patterns of team performance are often the appropriate representation in technology systems. Representing team performance as a linear summation of member contributions in tasks that do not conform to additive workflow structures not only misrepresents team effectiveness, it also muddies the ability to accurately evaluate and interpret the effect of HSI interventions.

As a workflow becomes increasingly intensive and team performance is more indicative of compilational rather than compositional forms of emergence, measurement and conceptualization should pursue non-additive combinations of individual-level inputs for team performance outcomes (Kozlowski & Klein, 2000). For example, in some tasks, the efforts of just one individual impact the entire team's outcomes (Steiner, 1972). In *disjunctive team tasks* only a single decision from the group is selected to represent the entire group's performance (e.g., decision-making teams, problem-solving groups); thus, team performance is often determined by the most productive/effective group member. Alternatively, *conjunctive team tasks* require that all members contribute to the team's performance outcome (e.g., distributed expertise teams, project teams) such that the least productive member impacts the team's maximum performance. Other performance environments necessitate variance in knowledge, personality, or other individual attributes (e.g., innovation tasks requiring high variance in expertise and ideas) or a mix of sharedness and variability (e.g., action-oriented tasks requiring general adherence to procedural protocols as well as the ability to develop new solutions to unforeseen problems) that are better represented via weighted performance algorithms or more dynamic representations (cf., Carton & Cummings, in press). Regardless of task environment though, the key implication for HSI is recognition that team workflow structure is critically important to accurately conceptualizing, capturing, and interpreting system performance.

Discussion

On and Over the Horizon: Building a Science of Team Design

Kozlowski and Bell (2013) compiled a list of 42 reviews covering the broad literature on team effectiveness published over the last 25 years. There is simply a wealth of actionable knowledge for improving team effectiveness and it should be applied. The basic logic of the IPO heuristic and its more dynamic successors is that team performance is enhanced when team processes are aligned with team task demands, thereby enabling effectiveness. Primary targets for achieving alignment focus on person (i.e., KSAs) and team (i.e., cognitive, motivational-affective, and behavioral) capabilities, with team / technology system design, team composition (i.e., selection) and team training being the primary levers for shaping these capabilities (Kozlowski & Ilgen, 2006). Given that training is often used as a “Band-Aid” to ameliorate poor system design choices, we believe that HSI should focus primary research attention on (a) developing team design principles, (b) identifying mechanisms underlying the emergence of team processes, and (c) enhancing team performance regulation and adaptation.

Team design principles. Good team design lays the foundation for team effectiveness, but good design necessitates integrating a set of concerns that are complex and, as yet, not well understood. Key concerns include (1) role design, (2) workflow interdependence structure, and (3) team composition. Role design involves allocating or bundling tasks to specific positions, which subsequently determines the requisite KSAs required for the role. Roles need to be linked together in a workflow structure that allows for efficient coordination of tasks and sub-goals in the overall technology system. Specific workflow structures impact the teamwork skills (generic and task-specific) required of team members, which influences selection decisions for staffing the team. Most typically, member selection is driven by the KSAs required for a given position; however, the issue is more complicated as individuals bring other characteristics that can either aid or inhibit effective teamwork. The challenge is considering the effects of the many potential patterns that can arise across members with respect to required KSAs, as well as other surface and deep differences that can fracture the team (de Wit et al., 2012; Mathieu et al., 2014).

Team design complexity thus arises because each of these three areas encompasses multiple variables and all are intimately correlated. Good design principles have to be able to identify relevant considerations within an area based on known contingencies and then achieve an optimal balance of implications across areas. From a research perspective, the primary challenge is that the number of relevant (primary) variables and potential contingencies (moderators) rapidly explodes. Conducting systematic research that can fully explore, model, and map this space has been problematic. Thus, existing knowledge within each area is limited and not integrated across areas. This is a primary research target.

Computational models and agent-based simulations represent a promising approach to researching this design problem (Caldwell, 2008; Kozlowski & Ilgen, 2006). A computational model can represent a full range of potential task allocations and candidate workflow structures. Agent-based simulations implementing the model can then be used to conduct "virtual experiments" that explore task allocations (e.g., human to human, human to system) to identify effective role and system designs before a team-technology system is implemented (Zachary, Campbell, Laughery, Glenn, & Cannon-Bowers, 2001). The cognitive modeling and engineering architecture for this practice is reasonably well developed. The ongoing challenge is to integrate and model implications of different patterns of team composition (Mathieu et al., 2014; Stewart, 2006) and informal fracturing around faultlines (Carton & Cummings, 2012).

Team process emergence. Good team design aligns team functioning, but design is not the only factor influencing these emergent processes. Much of the research supporting the important contributions of team processes to team effectiveness is based on static, cross-sectional research designs. Moreover, because they originate from individual characteristics and emerge to the team-level through interaction processes, the mechanisms of emergence represent a critical lynchpin to understanding the nature of team processes and their contribution to team effectiveness (Kozlowski et al., 2013). Thus, the mechanisms that shape emergence and the factors that influence them are ripe targets for research.

This is another area where virtual experimentation via computational modeling and agent-based simulation can yield major advances in understanding. Though there is some specialized use of simulations and/or behavioral observations, most examinations occur over limited time frames and primarily rely on retrospective self-reports of team functioning. Such methodologies are inherently limited in their ability to capture the dynamics of emergence. Computational modeling has no such limits. For a given phenomenon, it allows for theoretically relevant factors to be specified, appropriate levels or ranges of the factors to be computationally manipulated, and a full exploration of the theoretical space to be conducted via agent-based simulation (Kozlowski et al., 2013). Analyses can identify key factors that shape the mechanisms of emergence in ways that enhance team performance. Such factors then become candidate explanations that necessitate verification via human experimentation and evaluation. However, the modeling does the heavy lifting and is an efficient way to isolate a small range of design elements that have good application potential for shaping desirable forms of process emergence.

Team performance regulation and adaptation. Ultimately, system design specifications get set, team members get selected and trained, and the team is deployed. Now it needs tools to manage effort, improve processes, and adapt to the unexpected. Several streams of promising research amply demonstrate that teams can effectively regulate their effort and performance to accomplish goals if given appropriate tools and guidance; namely, appropriately calibrated goals, timely performance feedback, and a repertoire of adaptation strategies. For example, meta-analytic evidence supports the positive effects of team goal-setting on team performance (Kleingeld, van Mierlo, & Arends, 2011). Moreover, because teamwork implicates goals at multiple system levels, feedback plays a critical role in regulating attention to the accomplishment of individual goals as well as goals that contribute directly to team performance (DeShon et al., 2004). Finally, there is meta-analytic support for the effectiveness of an application tool called PROMeas (Pritchard, Harrell, DiazGrandos, & Guzman, 2008) that translates regulation concepts into metrics relevant to a team's setting. In sum, team regulation is a potent process for effective team self-management and adaptation in technology systems.

Remarkably, given the potential for technology systems to leverage team regulation, there has been little apparent effort to apply this actionable set of research findings. Many technology systems have the potential to access individually-oriented and team-oriented behavior at the behavior-/keystroke-level of precision. Communication patterns and even the content of communications can be rapidly assessed (e.g., Gorman et al., 2012). Even in more open systems not directly mediated by computer technology (e.g. firefighting, military combat teams), sensor platforms have been developed to capture patterns of collaboration and interaction (e.g., Olguin, Gloor, & Pentland, 2009). As such, it is possible to design systems that assess team member behavior and performance in real time and could provide specific, targeted, diagnostic feedback. We assert that such efforts would make individual behavior and team performance more transparent to team members, enable them to coordinate better, and promote better adaptation. Such a design necessitates putting the "human" at the core of HSI. We think such a perspective is essential for building a science of team design to support HSI and team effectiveness.

Case Study Analysis: Cyber-Security Team

An effective cyber-security team must be highly skilled, adaptive, and coordinated. All members of the team will need to possess high levels of technical expertise, as well as skills conducive to identifying patterns, condensing large-scale data, and making accurate and timely judgments regarding potential threats. Such groups are also likely to benefit from members with diverse sociocultural backgrounds that ensure the team has access to a wide range of cultural knowledge about norms, customs, and sociopolitical motivations relevant to potential sources of cyber-attacks. Though such surface-level diversity may improve the breadth of the team's knowledge resources, it may also create opportunities for subgroup fracturing along demographic faultlines that could impede efficient group communication and collaboration structures; as such, the seeds of possible relational conflict within the group should be monitored closely by leaders and rectified quickly if observed.

Decisions concerning how to most effectively structure teams in this context should be predicated on the degree of uncertainty in the environment as well as the amount of variability/specialization required among the team's roles and subtasks. A functional structure in which each member of a cyber-security team specializes in a limited number of task requirements (e.g., Member A responsible for security of all e-mail servers, Member B for all personnel databases, Member C for all satellite transmissions) may be most effective in contexts in which security threats are relatively stable or predictable and unique expertise is required to effectively monitor different avenues of cyber-attack. Alternatively, a divisional structure in which members take responsibility for broader, more encompassing task roles (e.g., Members A, B, and C are solely responsible for the security of e-mail servers, personnel databases, and satellite transmissions in sectors X, Y, and Z, respectively) may be more appropriate if cyber-attacks occur rapidly, without warning, and impact multiple modal technologies simultaneously. Effective HSI would thus support/help to offset the weaknesses in these designs by facilitating shared situational awareness and mental models, minimizing cognitive load bottlenecks, and maximizing coordinated information exchange and behavioral action.

Given the nebulous and specialized technologies faced by teams in this context, it is also likely that members of cyber-security teams will regularly interact through virtual means; such teams may also be more apt to integrate artificial/autonomous “teammates” who contribute to the team’s performance outcomes. Ensuring that such groups are capable of developing and maintaining efficient, effective processes for collaboratively planning for, acting upon, and evaluating events that occur in their task environment will be critical. Doing so will necessitate the development of formal procedures that permit team members to proactively and reactively regulate the flow of information, efforts, and resources to meet task demands based on the team’s workflow structures. Furthermore, team training initiatives that help members achieve convergent perspectives regarding how tasks should be accomplished will be imperative. Thus, as emphasized through this chapter, HSI directives will need to consider the multilevel nature of cyber-security teams’ performance requirements, their dynamic workflow structures, and their need for adaptive capacity in order to enhance team effectiveness in this context.

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Table 1. *Summary of Important Team Processes and Emergent States for HSI*

Team Process or Emergent State	Definition	Further Reading
Cognitive		
Situational awareness	Collective efforts to monitor the task environment, interpret its meaning relative to goals, and actively communicate those perceptions to facilitate sense-making and goal accomplishment	• Salas et al. (1995) • Salmon et al. (2008) • Salmon et al. (2010)
Shared mental models	Collectively shared mental representations of the key elements in the task environment	• Klimoski & Mohammed (1994) • McComb et al. (2010) • Cannnon-Bowers et al. (1993)
Transactive memory system	Distribution of knowledge storage and information processing functions across team members coupled with a collective awareness of "who knows what"	• Wegner (1987) • Moreland (1999)
Macrocognition	Process through which individual learning/information gathering activities are transformed into collective knowledge through information exchange, sharing, and the creation of tangible cognitive artifacts	• Fiore et al. (2010) • Kozlowski and Chao (2012a)
Affective/Motivational		
Cohesion	Individuals' psychological perceptions of attraction to a group (interpersonal cohesion), task commitment (task cohesion), and pride in a group that motivates team to remain together	• Festinger (1950) • Gully et al. (1995) • Beal et al. (2003)
Collective efficacy	Shared belief in a team's capability to organize and execute courses of action needed to achieve a given level of performance	• Gully et al. (2002) • DeShon et al. (2004) • Chen et al. (2009)
Conflict	Disagreement among team members concerning interpersonal incompatibility (relationship conflict); task content, ideas, or interpretations (task conflict); and/or how a task is performed and responsibilities distributed (process conflict)	• Jehn (1997) • de Wit et al. (2012)
Behavioral		
Behavioral processes	Activities related to communication, coordination, cooperation, and regulation among team members	• Rousseau et al. (2006) • Marks et al. (2001) • LePine et al. (2008)
Adaptation	Cognitive, affective, motivational, and behavioral modifications made in response to demands of a new/changing environment or situational demands	• Baard et al. (2014) • Burke et al. (2006) • Kozlowski et al. (1999)