Team Mental Models: Review, Analysis, and Integration

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Abstract: In recent years an innovative sociocognitive perspective for exploring teamwork effectiveness has been advocated by numerous researchers. This perspective examines ways by which team members develop mutual understanding. The general idea is that team effectiveness will improve if team members hold adequately shared cognitive representations, often termed as team mental models. Although this theory has significant potential for explaining teamwork effectiveness, there are several conceptual inconsistencies that impede its developmental potency. The purpose of the current article is to review and integrate the accumulated knowledge, thus facilitating future theoretical and empirical work. The paper reviews interdisciplinary groundwork relating to team mental models, analyzes recent empirical findings, and develops a conceptual framework from which conclusions for future research are drawn.

Keywords: Team, Mental models, Social cognition.

INTRODUCTION

Almost a decade ago Hackman and Morris [1] claimed that upon facing genuinely important tasks, organizations tend to assign and solve those tasks through group activity. Indeed, for the last several decades, organizations have increasingly turned to the usage of teams as an important strategy for successful management [2]. Teams have become an extremely popular work design [3] and a fundamental component in modern industry [4]. As Watson [5] asserted, the effective use of teams is America's best hope for competing in the worldwide marketplace. Organizations adopt team-based work structure to better utilize expertise, cope with effects of increasing workload, and maximize the use of sophisticated technologies [6]. Teamwork has become a critical element of almost all organizations and a topic of great interest in the research community [7]. Hence, it is of no surprise to find a very extensive and comprehensive flow of studies that deal with the general theme of teamwork and its accompanied phenomena (for review see [8]).

The nomenclature *team* is used throughout this paper, although much of what we know about teams derives from research on groups, and to say the least they share similar dynamics and antecedents [9]. Teams are viewed as a private case of small groups that is more structured and task-oriented. They possess more task interdependencies, require higher levels of coordination, utilize intensive communication, and demand differentiated role assignments [10]. Teams are more than a sum of members' collective efforts. They represent a planned conduct for effectual synchronized output [8] that allow members to share the workload, monitor the work behaviors of others, and develop expertise on performing subtasks [11].

Despite considerable theoretical and empirical work, the saying that little is yet known about teamwork effectiveness has almost become a maxim [12]. Regardless of the significant role that teams play in industry, science has made woefully little progress in understanding the factors that contribute to effective team performance [13], although this issue has been explored through various research strategies (e.g., [14]). Recently, attempts to consolidate socio-cognitive approaches to the study of teams have gained some support (e.g., [11]). These innovative approaches examine ways by which dyads and groups develop and utilize collective meaning and understanding. Growing evidence indicate that the existence of shared mental models among team members has a positive effect on team processes and effectiveness [15]. These models emerge as team members interact to make sense of their surroundings and cultivate mutual beliefs about members' common goals [16]. In a sense, most of these studies are variations and expansions of McDougal's [17] concept of *group mind* [18] and advances of previous conceptualizations made by other seminal authors (e.g., [19-22]).

Contemporary deliberation suggests that team effectiveness will improve if team members hold adequately common cognitive representations of task requirements, other team members, equipment, and situation (e.g., [23]), often termed as *team mental models* (TMM). This concept, originally introduced by Cannon-Bowers and Salas [24], encompasses several specific dimensions in teams' behavior. It is postulated that TMM can account for the fluid, implicit coordination frequently observed in effective teams, and especially those that function in complex, dynamic, ambiguous, and unpredictable situations [25].

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The TMM approach explains team performance through the mental models of individual team members [26]. Through sharing these models, members accumulate socially constructed cognitive structures that represent collective knowledge or beliefs about the environment and its expected behavior [15]. Collaboration in team members' mental models can lead to greater shared explanations and anticipations of the situation and each other's actions and needs. In turn, these processes induce improved coordination, communication, and other effective team behaviors [27].

Although the general notion of shared cognition has been known for over 20 years, it has been applied to teams only recently [28], and already has several conceptual inconsistencies that affect its developmental potency. In the words of Cannon-Bowers and Salas [28] "the term has been used to mean so many different things, that it may be on its way to being meaningless" (pp. 200-201). To illustrate, one can find numerous phraseology for the shared cognition phenomena, such as: distributed cognition [29], socially shared cognition [30], shared mental models [12], group cognition [31], team mental models [9], teamwork schemas [32], shared reality [33], shared beliefs [34], and team knowledge [35]. This diversity can be ascribed to the elusive and eclectic nature of mental phenomena [36], as well as to the novel usage of cognitive approaches in teams' study [9].

The purpose of the current article is to provide a review, analysis, and integration of both conceptual and empirical developments of TMM. First, the historical roots from which the concept of has been drawn, as well as its interdisciplinary groundwork, will be reviewed. Second, I will portray a number of pivotal ideas evolved thus far in this research domain. Third, I will provide a conceptual framework and draw from it conclusions for future research. Finally, I will summarize contemporary empirical findings and demonstrate their implications for the current state of knowledge.

I. EVOLUTION OF TEAM MENTAL MODELS

Although traditionally cognitive psychology has focused on the individual and delineated processes by which the mind perceives, manipulates, and interprets information [37], it is agreed today that cognition phenomena exist only in relation to the context in which the individual operates [38]. As Klimoski and Mohammed [9] have stated "cognition is almost always a social phenomenon" (p. 406). Thus, the social environment became a generic component in various cognitive phenomena broadly referred to as "*Social Cognition*."

Fiske and Taylor [39] defined social cognition as "the study of how people make sense of other people and themselves" (p. 1). In recent years the social cognition school has gained ascendancy as the preferred rubric under which a wide variety of research topics are explored [40]. As Thompson [41] stated "the world's most important social problems have been analyzed through the lens of social cognition paradigm" (p. 3).

Contemporary research extends beyond the relations between the knower and the object of knowledge, while exploring the tripartite relations between the individual's cognition, the social cognition, and the object of social knowledge [42]. Some claim that this paradigm shift has been partially stimulated by the growing dissatisfaction with individual social cognition, while others are more skeptical merely perceiving it as "old wine in new bottles" ([41]; [18]).

As part of this paradigm shift, a new look at social cognition has emerged, which involves shared knowledge among dyads and groups [43]. The basic assumption underlying this modification suggests that group-level cognitive processes are analogous to those that occur at the individual level [44]. It maintains that the individual unit of analysis is not always the most appropriate one [26], and that most cognitive products should be viewed as outcomes of joint cognition constructed by a number of persons [37]. This line of thinking suggests that the 'mind' is 'located' in patterns of connections between individuals and in the interrelations between their group activities ([44]; [45]). Evidences from a wide spectrum of small group research, ranging from young children play groups (e.g., [46]) to top management teams (e.g., [43]), have supported these claims.

In light of these ideas, Larson and Christensen [40] re-defined social cognition, and stated that "at the group level of analysis, cognition *is* a social phenomenon" (p. 6). These authors hypothesized that the term social cognition can be applied at the group level of analysis to refer to social processes that relate to individual cognitive processes for the purpose of creating a group-level intellective product. Thus, cognition should be conceptualized as a product of social interchange that is constructed, shared, and distributed during the course of interaction [47]. This approach represents a stage of evolution as social

cognition grows to encompass group research [41], and an understanding that social cognition is critical for the understanding of group performance [48]. Given this, teams' researchers, in their endeavors to resolve the effectiveness enigma, have begun exploring possibilities for utilizing the shared cognition paradigm.

Cannon-Bowers and Salas [28] contend that the concept of shared cognition has an explanatory power and can separate effective from ineffective teams. They postulated that effective teams are composed of members who have similar or compatible knowledge structures that guide their coordinated behavior. In addition, they see in the shared cognition concept a diagnostic tool for practitioners who wish to establish a better understanding of the elements of effective teamwork.

II. GROUNDWORK OF MENTAL MODELS

During the years the cognitive school has proposed a number of hypothetical knowledge structures for organizing information in meaningful conducts. One of these cognitive constructs is the *Mental Model*. Applying mental models to teams appears to be quite natural since teams are seen as complex social systems, and mental models are offered as powerful explanatory mechanisms for understanding and promoting effective performance in complex systems (e.g., [49]; [27]). In order to gain understanding on shared cognition processes in teams, the current section will briefly portray the accumulated knowledge concerning mental models.

Mental models were offered as symbolic representations of a system and its expected behavior [50]. They are seen as internal hypothetical structures that select, abstract, interpret, integrate, and predict human behavior. Similar to schema and other cognitive structures, mental models stem from perception [51]. They are often viewed as naive or intuitive theories (e.g. [52]) that people construct as they visualize the world and develop working models of it in their mind [51]. Individuals use mental models to explain a perceived phenomenon [53], and their primary function is to transform the originally perceived into conceived [21].

Johnson-Laird [51] argued that people have an innate tendency to utilize mental models since they need to understand the system within which they operate. This is done by constructing a series of meaningful symbolic representations and casual models based upon integrated information from all the senses and from general knowledge [55]. Mental models cognitively represent a system and the individual's interaction with that system. Since these interactions are not static, neither are the mental models [49]. Mental models can be manipulated, thus enabling people a predictive ability [51]. They develop over time based on the interaction with the world and previously obtained experience [53]. In this sense, mental models should not be viewed as an exact facsimile of the objects they represent. Rather, they should be conceptualized as a process of reconstruction of innovative knowledge configurations [54].

Johnson-Laird [55] proposed that the modern formulation of the mental models can be attributed to Kenneth Craik [56]. Craik perceived a model as a system that holds similar relations and structures to the process it imitates, and proposed that a mental model is a dynamic representation, or simulation of the outside world. Johnson-Laird [55] stated that most cognitive scientists adopt Craik's postulations, and that currently mental models are viewed as a fairly well-accepted psychological notion of how skilled performance is organized. For the purposes of the current paper I shall employ Moray's [57] observation of mental models, which merge the different approaches. Moray wrote that "the canonical form of a mental model, as indeed of any model, is a homomorphic mapping from one domain to another, resulting in an 'imperfect' representation of the thing modeled" (p. 283).

In recent years there has been a massive growth in diverse and multifaceted research concerning mental models. Wilson and Rutherford [58] pointed out the inconsistent use of the term mental model, and stated that mental models are all things to all people. However, they also asserted that mental models have been introduced as explanatory mechanisms in a variety of disciplines. Rouse and Morris [36] claimed that "it is hard to explain many aspects of human behavior without resorting to a construct such as mental models" (p. 349), and Espinosa and Carley [59] claimed that humans develop mental models for just about everything. Cańas, Antolé, and Quesada [60] suggested that currently research on mental models is problematic due to great confusion concerning their definition, and that this problem has been stressed for a long time but still has not been solved satisfactorily.

The concept of mental model should be applied to particular types of knowledge and to particular mental

functions. Namely, mental models, as opposed to knowledge in general, are working-memory constructs that support reasoning [61]. They are the basic structure of cognition in representing objects, state of affairs, sequences of events, the way the world is, and the social and psychological actions of daily life [51]. They evolve when active memory objects are mapped into components of the real world phenomenon; then these objects are recognized and connected to form a model of the situation. Subsequently, they are used as a foundation for additional reasoning [62].

In light of Rouse and Morris [36], three core functions of mental models can be delineated. First, mental models serve as internal mechanism for generating *descriptions* of concepts in terms of form and purpose. This fundamental function implies that mental models serve as the basis for recognizing and remembering the relationship between concepts [63]. Second, mental models serve to *interpret* the surroundings, thus enabling us to draw inferences, understand phenomena, and establish sensemaking mechanisms (e.g., [64]). Third, mental models serve to *predict* future states and provide a source for a person's expectations. Through imagining the future state of the system, given its initial condition [52], we can experience events vicariously [51], and predict the consequences of actions prior to actual performance. Wilson and Rutherford [58] see in this predictive function the silent difference between mental models and other knowledge structures and argue that, lacking its dynamic computational ability the notion of mental models is redundant.

III. PIVOTAL ISSUES OF TEAM MENTAL MODELS

In the current section I shall delineate how mental models are applied to teams and summarize a number of pivotal issues of TMM, including their content, primary functions, and antecedents. Finally, I shall portray several sharedness issues and demonstrate their importance in enhancing teamwork effectiveness.

Applying Mental Models to Teams

Thompson and Fine [18] posited that the concept of shared mental models at the group level evolved out of the concept of mental models at the individual cognition. Walsh [65] postulated that these emergent collective knowledge structures would act in the same manner as individual knowledge structures. Shared mental models are defined as collectively constructed mental models and their casual connections [15]. In contrast to individual mental models, these models are socially constructed and rely on consensus and agreement [66]. Hence, the concept of mental model becomes relevant and of particular importance for teams' research [60].

The interest in mental processes in groups has a long history in social psychology. From the onset of group research, scholars like McDougal [17] tended to refer to the existence of a 'group mind' [9]. Evidence for shared mental processes in groups can be traced back to Mead's [67] communication approach and his assertions concerning social reality construction and cooperative behavior guided by shared notion of task processes and activities. Adjacent aspects of shared cognition phenomena can also be found in the *deindividuation* (e.g., [68]) and *crowding* effects (e.g., [69]). In actual group setting, one can trace mutual understanding processes in Sherif's [70] work on norm formation in light of the autokinetic effect, and in subsequent research on social norms and roles (e.g., [71]). Wegner's [22] concept of *transactive memory*, which was originally conjectured to account for intimate couples' behaviors, can also be considered as a conceptual root of shared mental models as this theory has been applied to group research (e.g., [72]). Another illustration of mutual exploitation of mental resources in groups is manifested in the *team-mind* construct that is composed of team consciousness, preconsciousness, and memory [73]. The metaphoric articulation of group as an information processing unit (e.g., [74]) can also reflect an effort for delineating shared cognition in groups. Finally, it seems that the broad concept of team knowledge induces a wide array of perspectives (e.g., information sharing, group learning), and provide considerable insights into shared cognition processes in groups [25].

These theoretical examples are merely illustrations of the copious literature on the global issue of shared mental models. One can find further support for the relevance of mental models as a valid explanatory mechanism in teams by carefully examining their roles in estimating the state of systems, developing and adopting strategies, selecting proper actions, determining results, and understanding phenomena that occur as the task progresses [63]. Thus, it is of no wonder that Paris *et al*. [8] posited that the next frontier in research on teams must capture cognitive phenomena if we are to achieve progress in understanding team functioning in complex systems. Thus, in recent years a renewed interest in the collective aspects of cognition has emerged [47], as researchers have begun directly testing the TMM

hypotheses [12]. Shared mental models in teams have become the hallmark of the nineties [8], and the notion of shared cognition in groups has become one of the most promising areas in socio-cognition research [37].

Cannon-Bowers *et al*. [12] define TMM as "knowledge structures held by members of a team that enable them to form accurate explanations and expectations about the task and to coordinate their actions and adapt their behaviors to the demands of the task and other team members" (p. 228). Team members who share mental models are expected to be able to predict the behavior and information needs of others more accurately [75], and implement more efficient communication strategies [76].

These potentially induced benefits are of great importance since they tap into the core of on-going interaction processes that take place in teams. Interruptions in these processes affect the flow of communication and harm coordinated behavior, which in turn threaten the effectiveness of a teams' performance [77]. Although certain levels of coordination and synchronization are essential in virtue every aspect of social life [18], in complex situations the need to coordinate members' activities, subtasks, and resources is accentuate [59].

Today's teamwork is certainly a complex situation. It is characterized by time pressure, multifaceted tasks, rapidly evolving and changing information, and acute uncertainty and ambiguity [78]. In addition, telecommunication and groupware technologies have made geographically distributed and asynchronous collaboration more feasible and popular [59]. Contemporary teams depend upon the abilities of members to effectively coordinate their actions [79], integrate information and resources, and adapt to changing task demands [27]. However, under extreme conditions explicit coordination simply takes too much time [53], and opportunities for overt communication and long term structured planning are restricted. Thus, team members are obligated to coordinate their action through implicit cues and to further develop their predictive and anticipative capabilities [73].

Espinosa and Carley [59] proposed that in the traditional research literature coordination was viewed as an outcome of team and task organization, as well as of communication processes and mechanisms (e.g., [80]). While traditional theories have addressed coordination by focusing on explicit mechanisms, contemporary theories look into other more implicit mechanisms. The switch from explicit to implicit coordination is the primary adaptation mechanism that allows teams to preserve and improve their performance [81]. It is manifested in situations where members offer each other the necessary information without an explicit request [76, 82]. Presumably, this implicit coordination rest upon what Ickes, Stinson, Bissonnette, and Garcia [83] termed as *intersubjectivity* -- an ability to accurately infer the thoughts and feelings of others. Intersubjectivity is developed through several cognitive mechanisms, such as verbalizing and interpreting, during which individual mental structures are being collaborated, and a shared understanding of what is being discussed or worked on is established [37]. Eden, Jones, Sims, and Smithin [84] argued that this mechanism is critical in considering individual and shared knowledge in teams and in increasing members' commitment.

Espinosa *et al*. [85] asserted that the above mentioned implicit processes are based on team cognition. Namely, absence of adequate shared mental models is believed to be one possible source of coordination difficulty in complex tasks [79]. To illustrate, Minionis, Zaccaro, & Perez [86] reported that when subtasks could be completed independently, shared mental models did not increase team effectiveness. However, in interdependent situations their contribution was indeed significant. In sum, the ability to reduce process errors and adapt effectively to evolving needs and unexpected events, strongly relies upon holding a degree of consistency between the various mental models held by team members [79], and this ability appears to have a growing influence in contemporary teamwork.

The Content of Team Mental Models

Walsh [65] stated that the study of the content of knowledge structures is important for applied research, and probably should be the first step of inquiry. He asserted that one cannot investigate these structures without identifying first the information environment they represent. Druskat and Pescosolido [15] maintained that the content of shared mental models is of central importance due to its impact on team performance. However, little is known about the specific content of effective TMM [87].

In general terms, TMM conceptualize what is going on among team members or their assessment of the stimuli [9]. Theory and practice have outlined numerous skills and abilities that underlie teams' behaviors (e.g., [8]). While some of these behaviors are quite explicit and observable (e.g., overt communication), others are

more implicit and complicated (e.g., predicting teammates needs). As mentioned earlier, the notion of TMM was offered primarily in order to tap into these more complex and latent behaviors.

In an attempt to clarify and organize the content that is embedded in the TMM, several categorizations have been introduced over the years. Espinosa *et al*. [85] maintained that TMM hold individual knowledge, which is necessary for performing each member's own task and responsibility, and shared knowledge, which is necessary to coordinate members' activities as a consistent body. Converse *et al*. [75] proposed that team members form mental models of the external environment, team environment, teammates, and task. Cannon-Bowers *et al*. [12] hypothesized the existence of multiple mental models of task and team, and distributed them into four categories: equipment models, task models, team interaction models, and team models. Cooke *et al*. [48] claimed that the content of TMM can be declarative (i.e., facts, concepts), procedural (i.e., steps, sequences), or strategic (i.e., task strategy). Cannon-Bowers and Salas [28] suggested four types of TMM: task-specific, task-related, teammates' knowledge, and attitudes or beliefs concerning teamwork.

In order to integrate and provide a comprehensive view I offer a quadric-dimensional system for organizing the content of TMM. The basic dimension of this system is the instrumental-socioemotional dimension. This dimension captures the essence of teamwork since members contribute to the team's output by: (a) performing task or instrumental behaviors, and (b) performing social and emotional behaviors. While the former delineates the extent to which an individual contributes to the execution of the task and the successful completion of the group goals, the later delineates the extent to which an individual contributes to the successful interaction among teammates, morale, and satisfaction of emotional needs [88]. Aside of this fundamental dimension, the quadric-dimensional system encompasses three other dimensions: personal-collective dimension, explicit-implicit dimension, and generic-specific dimension (see Figure **1**). Although the quadric-dimensional system can be separated into eight continuum lines, for the purpose of the current discussion this degree of elaboration is sufficient. Also, it should be noted that these dimensions are not orthogonal and an absolute separation of them is conceptually erroneous and is applied here merely for didactical purposes.

(1) Instrumental-Socioemotional Dimension: The instrumental end of this continuum encompasses specific knowledge about the task, knowledge that is relevant to the task, task strategies and tactics. It suggests that team members should

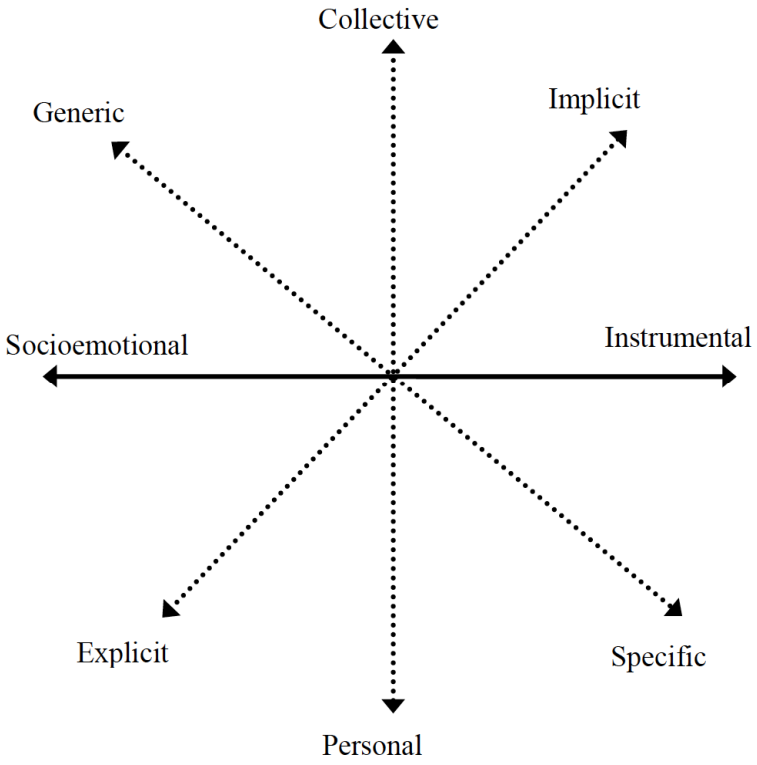

Figure 1: A Quadric-Dimensional System for Capturing The Content of Team Mental Models.

share knowledge of specific procedures, sequences, actions, and strategies that are necessary to perform the team task [28]. The socioemotional end of this continuum encompasses interpersonal knowledge, information about teammates, conflict management, cooperation, commitment, and support. It suggests that team members need to understand one another and to know each others' preferences, strengths and weaknesses [28]. Such knowledge is crucial for team effectiveness since it allows members to tailor their behaviors in accordance with mutual expectations [89].

(2) Personal-Collective Dimension: The personal end of this continuum encompasses individual characteristics, such as personality dimensions relevant for teamwork, skills and abilities concerning task and equipment operation, and knowledge driven from past experiences in teams and in other social interactions. To illustrate, Rom and Mikulincer [90] found that past experience in teams, personal attachment tendencies, emotions, and cognitive attitudes towards teamwork are closely associated with the performance and appraisal of team members. The collective end of this continuum encompasses cultural values, norms, attitudes, and belief systems that are relevant to teams. It also encompasses structural variables of teams (e.g., size, composition, formal rules, roles), and process variables (e.g., cohesion, communication, norm formations). This shared knowledge enables members to achieve compatible interpretations of the environment, reach higher levels of cohesion, and enhance motivation and consensus [28]. Due to the central role of the collective knowledge in team performance, I will elaborate on this issue in the section concerning knowledge sharedness among team members.

(3) Explicit-Implicit Dimension: The explicit end of this continuum encompasses know-how information such as operator knowledge, formal roles in the team, overt strategies, and evident information concerning other team members. The implicit end of this continuum encompasses tacit knowledge of an evaluative nature. Mohammed, Klimoski, and Rentsch [91] distinguished between what members "know" to be true (knowledge structures) and what they desire, prefer, expect, or demand (belief structures). These belief structures are taken for granted and not given explicit attention. They converge in the team out of salient shared experiences and common set of external influences [92]. Mohammed *et al*. [91] suggested that these beliefs describe what members *feel*, as opposed to what they *know*. Although they are not the conventional explored knowledge structures, their impact on team performance can be crucial. For example, Gibson [93] found a positive relationship between group efficacy (a group's belief regarding its ability to perform effectively) and group effectiveness. Cannon and Edmondson [34] maintained that tacit beliefs about how to respond to mistakes, problems, and conflicts affect members' ability to learn from failure. Consequently, these beliefs influence team's performance. Edmondson [92] demonstrated that team psychological safety (i.e., a shared belief that the team is safe for interpersonal risk taking) was associated with learning behaviors. Druskat and Pescosolido [15] conjectured that TMM encompass core concepts of psychological ownership, need for learning, and need for heedful interrelating. These concepts underlie effective TMM and induce higher team performance. For example, the psychological ownership makes members feel that the team actions and outcomes are under their authority and responsibility. In turn, this shared belief encourages ownership behaviors and enhance the desire to engage in learning and development.

(4) Generic-Specific Dimension: The generic end of this continuum encompasses knowledge that is more stable and applicable to most teams. This knowledge is consistent across particular instances of teamwork, and is considered as meta-knowledge or core-knowledge [32]. It holds general information, attitudes, skills, abilities, and other stable features, and it is sometimes considered as pre-task knowledge that resides in long-term memory [94]. Through this high-leveled knowledge people retain information concerning global themes of teamwork, such as cooperation, interdependence, and commitment. These models appear to be more directly linked to team performance than task-specific models [11], and sharing them enables teams to engage in processes that lead to team effectiveness [15]. The specific end of this continuum encompasses

concrete knowledge that tends to be more complex and to vary in light of particular team types, teammates, and tasks [6]. This knowledge tends to develop and transform while the team operates [95]. Its content is dynamic and in a constant state of flux, and it incorporates the specific characteristics of the current situation [48].

In sum, considering the diversity of teams' circumstances, and in light of Markman and Gentner [52] and Johnson-Laird [51] it seems that multiple TMM simultaneously exist in the minds of team members at any given point of time. These models are probably located at different locations in the quadric-dimensional space that is portrayed above. Future research should explore content issues more explicitly and study the interactions and reciprocal influences between them.

The Functions of Team Mental Models

Earlier in this review I delineated three core functions of mental models that allow individuals to describe, interpret, and predict their environment [36]. In accordance with these basic functions Rasker *et al*. [53] suggested that TMM provide members with a common problem space in which they can explain the behavior of fellow team members and predict their information needs. In the current section I shall elaborate these functions and outline their association with development processes that occur in teams.

Initially, TMM serve as a means to construct the social reality and give it some meaning and coherence. Negotiation of shared and idiosyncratic understanding of reality is considered to be an important process in teams [84]. Through this process, members develop a cognitive consensus regarding how key issues are defined and conceptualized [25]. The emergence of shared meaning is hypothesized to precede learning and action in groups [66]. Its purpose is to provide the foundation for mutual understanding that will facilitate coordination [96] and communication [97]. A shared meaning clarifies why the team is needed, what it should do, who should be involved, etc. These questions are influenced by the basic assumptions of teammates, which define what is perceived to be appropriate behavior, process, and outcome [98], and they tend to primarily arise as members first come together. In addition to sharing concrete and explicit knowledge of teamwork and taskwork, members hold a common conception of the assumptions underlying issues of significance [25]. Holding a collective belief structure, aside from embodying beliefs and self interests, facilitates problem definition, enhances alternative generation, and affects the speed, flexibility, and implementation of decision making [99]. These processes become an essential factor for group socialization and indoctrination (e.g., [100]).

Beyond their descriptive role and in order to facilitate reality construction and sense making, TMM serve as a means to explain and interpret the social environment. In other words, additionally to delineate '*why*' and '*what*', they also evaluate '*how*' teamwork should be conducted, for instance in terms of process variables such as communication, norms, and behavioral roles. Holding shared ways of perceiving and explaining situations can improve team performance and help members arrive to a common ground that will facilitate their coordination [27].

Finally, TMM serve as a means to predict future conditions of the team through creation of casual events associations. This function enables teammates to predict specific outcomes, anticipate members' reactions, and evaluate potential consequences and best ways to accomplish tasks [58]. Volpe, Cannon-Bowers, Salas, and Spector [101] indicated that predicting each others' behavior is a significant element in enhancing teamwork competency. Rouse *et al*. [27] proposed that teams with shared mental models require less overt planning time because members can predict what others will expect from them. Accordingly the need for verbalization decreases. Cannon-Bowers *et al*. [12] view mutual expectations of task and team as the most important function of TMM since it allows teammates to coordinate, adapt, and predict other members' needs and behaviors.

Examining the above presented functions can imply that they evolve in a graduated manner and in parallel to the team's development. Initially, members construct the team reality and acquire some common descriptive knowledge. In a sense, this can be equivalent to preliminary developmental stages, such as the "forming" stage (e.g., [102]). Indeed, McCaskey [103] stated that "the work of a group in its early stages includes forming a publicly held map that is generally agreed to by all its members." That is, knowledge of why the team has come about is likely to start the development process of mental model [9] and it is most dominant at early stages. Subsequently, members assemble mutual explanations. This process can be ascribed to later stages, such as the "norming" stage where a deeper sense of shared mental model exists [9]. Consequently, members begin to accumulate

shared anticipations and predictions of future states. Indeed, Cannon-Bowers *et al*. [12] suggested that common explanations among members lead to the development of shared expectations. This is more likely to emerge after the team has gone through some form of transition and consolidation. Adopting this view can clarify why members in mature or generative teams can retain and exploit knowledge that has a synergistic effect [9], and are able to communicate and synchronize their action implicitly.

Antecedents and other Influential Factors of Team Mental Models

Traditionally, researchers operating under the team cognition paradigm hypothesized that members' knowledge structures are related, directly or indirectly, to team effectiveness (e.g., [12]), and thus emphasized the consequences rather then the antecedents, or other influential factors, that underlain TMM [104]. It seems that there is a paucity of literature investigating the determinants of TMM [91], although delineating factors that affect their content and cognitive organization is of major importance (e.g., [100]).

Druskat and Pescosolido [15] maintained that mental model theorists discuss three primary sources of information through which mental models emerge: team member history or prior experience, team task, and organizational environment. In this section I shall review these information sources, and other antecedents, that influence the evolvement of TMM while distinguishing between individual and collective factors.

1. Individual Factors

The study of individual characteristics and their affect on teams dates back decades ago (e.g., [105]). Contemporary studies explore diverse individual issues in teams, such as members' knowledge, skills, and abilities (e.g., [3]), attitudes (e.g., [90]), and personality attributes (e.g., [106]). However, to date there have been few empirical efforts to tap into the role of individual characteristics in TMM, even though these factors have been proven useful in predicting team performance.

Cannon-Bowers *et al*. [12] proposed several individual-level variables that play a meaningful role in establishing TMM. Among these factors they include knowledge, skills, and abilities (KSA) of team members, personality tendencies, attitudes, motivations, preferences, styles, and goals. Rentsch and Klimoski [104] viewed demographic characteristics of team members (e.g., gender, age) as important variables that can influence the evolvement of TMM. A number of researchers maintained that personal experiences, aside from being a source of knowledge for others, can directly shape TMM (e.g., [32, 60, 107]). For example, Rentsch and her colleagues claimed that individual models are shaped by one's history and prior experience in teams. She found that TMM held by high experienced individuals tended to be more consistent and abstract, better articulated, concise, and elaborated. In turn, these effective knowledge structures provided better mechanisms for coping in complex team situations and interpreting new experiences.

2. Collective Factors

With regard to collective factors that affect TMM I divided the team's psychological environment according to several authors' categorization (e.g., [108]) into structural, process, and environmental variables. While structural variables are given to team members, process variables evolve as the team operates and as members interact. Environmental variables, on the other hand, serve as an external context that contains local factors (e.g., organizational stress), and global factors (e.g., general culture). I shall have more to say on these distinctions in Section four, where I introduce a theoretical framework for TMM.

2.1. Structural Factors

Since there are numerous structural variables that operate in teams, I shall exemplify in the current context only a few that have been proven useful in delineating the evolvement of TMM. For instance, team size has been hypothesized to influence mental models due to the fact that as the team grows larger opportunities for interactions among members decrease and less knowledge sharedness is likely to occur [104]. Task design and degree of role differentiation have also been considered critical factors that affect the amount of team interaction, which again can influence TMM [109]. Level of task interdependence among members has been suggested to have an impact on TMM since it dictates the amount of cooperation and synchronization [15]. The degree of task routine has been argued to influence TMM since unpredictable tasks involve high levels of uncertainty that require stronger mental capabilities [15]. Finally, team composition and especially demographic diversity has been associated with an increased attitudinal and cognitive diversity that affect TMM [110].

2.2. Process Factors

Like in the case of structural variables, there are numerous process variables that operate in teams, but only some were proven useful in predicting the evolvement of TMM. For example, Rentsch and Klimoski [104] suggested that normative variables, such as trust and cooperation, play a significant role in the formation of shared mental models. Several authors argued for the importance of communication processes in fostering TMM (e.g., [97]; [95]; [78]; [53]). These authors view overt communication in teams, and participants' awareness of the shared knowledge, as important factors in team performance. They argue that explicit communication enables members to exchange information, coordinate, monitor performance, provide feedback, create plans and strategies, and promote development of TMM. Blickensderfer, Cannon-Bowers, and Salas [111] demonstrated that intra-team feedback (i.e., members giving each other feedback) plays an important role in adjusting and developing shared mental models because it supports the development of shared expectations and explanations of task and roles. Cohesion was also found to be an important antecedent that facilitates the emergence of TMM as cohesive teams are more likely to share tacit understandings and values [43]. Cohesion tends to increase communication among teammates [9], encourages active participation in team's conversations, and enhances self disclosure or collaborative narration (e.g., [112]). In turn, these processes provide members with predictive and explanatory knowledge [113]. Successful heterogeneous teams create over time an emergent culture that offers a common sense of identity. This hybrid team-specific culture facilitates interaction and performance [114]. Finally, in light of the previous discussion concerning the evolvement of mental models in parallel with the team's developmental stages, it seems that the development stages and the time that members spend together can serve as a means to modify TMM.

2.3. Environmental Factors

Groups rarely operate in a vacuum [100] and teams are complex adaptive systems that interact with and are influenced by their organizational environment [15]. Since mental models tend to remain rather stable until contradicted by incoming external data [51], it is likely that environmental factors play an ongoing role in the development and endurance of TMM. For example, Kraiger and Wenzel [87] argued that organizational culture has a strong impact on the development of TMM. Peripheral forces, like external competition, were found to influence the emergence of shared knowledge structures (e.g., [110]). Incoming information from the organization shaped TMM, particularly if those models were weak and tentative [15]. Finally, selection processes, socialization, and turnover affect the speed and course of TMM development [9].

In sum, thus far the consequences of TMM were given the primary emphasis in theory and research. In light of the preceding ideas, it appears that the antecedents of TMM offer a wide and fertile array for future research.

Sharedness

The sharedness issue cut to the core of shared cognition [28] since only through sharing knowledge do we know it actually exists [115]. The fundamental assumption underlying TMM theory and practice suggests that the higher the convergence in members' mental models, the better the team performs [15]. Studies have demonstrated that information processing problems and conflicts within teams tend to arise when individuals hold different mental models [74], and that team members with different mental models about how tasks should be completed may experience difficulties in coordinating their activities [109]. Therefore, an analysis of knowledge sharedness issues in teams can potentially maximize teamwork performance [94]. In the current section I shall tap into these issues and provide a categorization for sharedness states in teams.

Initially, it is important to clarify what is the mental substance that is shared in the collective representation of team members. It appears that members can hold shared beliefs, understandings, and other cognitive contents, but they may also share mental processes, frames of reference, and cognitive categories. While agreement around broad frame of interpretations provides the collective meaning needed to move toward action in teams [116], common definitions of problems, goals, information cues, strategies, and roles [95] allow group interaction to proceed in a well-coordinated manner [117]. Nevertheless, the benefits of holding similar knowledge structures are dependent upon the degree to which this knowledge is actually accurate [6]. Team members can perfectly share information that is ultimately wrong [118], and sharing inaccurate knowledge can mislead team action and induce several negative outcomes.

Moreover, the literature shows that it is not suffice for members to share knowledge, but they should also

be consciously aware that they hold it in common (e.g., [9, 45]). It can be postulated that while some aspects of team knowledge require an implicit tacit agreement in order to enter members' shared knowledge structures, others involve overt communication and more explicit articulation in order to transform into collective knowledge constructs. Since socioemotional knowledge in teams is often developed from an emergence of unspoken agreement, I suggest that it resides in lower levels of awareness. On the other hand, instrumental knowledge is frequently manifested in explicit communication during team action, and thus probably resides in more conscious levels among team members.

Although the analysis of shared knowledge processes has a long tradition in group research (e.g. [119, 120]), there is a certain ambiguity inherent in the sharedness term, and the literature is generally vague in specifying which meaning of sharedness is being discussed [9]. A systematic inquiry of knowledge sharedness in teams has begun only recently [48] following the recognition that exploring the various information types to be allocated in each sharedness category is crucial for teamwork effectiveness [25]. Given this, I shall now portray several categories of knowledge sharedness in teams, which can be allocated along a similarity continuum (see Table **1**). This continuum corresponds to Stasser and Titus's [121] assertion that knowledge in groups tends to fall between the extremes of information being completely shared and information being completely unshared. However, the extreme cases in which team members' knowledge is identical or completely distinct are highly unlikely [118], and there are probably different levels of sharedness in members' mental models [91]. Thus, it is more appropriate to describe team knowledge as points on a continuum [48] ranging from 'exactly the same' to 'the exact opposite', passing through 'completely different' [26]. In the remainder of this section I shall delineate different sharedness categories while allocating them along the similarity continuum.

To begin with, some portions of knowledge do not need to be shared and can be treated similarly to other private knowledge structures. Much of the information about system structure and decision processes resides in the mental models of participants, where it remains tacit, subjective, and personal [122]. I term this category *private knowledge* following the semantics of Langfield-Smith [123].

Private knowledge depicts sets of interrelated information about various domains that are specific and unique to the individual and not shared by others. Knowledge that is embedded in this category is required only by the particular individual performing a specific role [48]. Sharing this type of knowledge is unnecessary for team processes. This is particularly true in tasks that require lower levels of interdependencies where sharing is not as important [87], and holding unique knowledge fragments can ultimately enhance teamwork effectiveness.

Aside from private knowledge, the literature provides us the basis to postulate different attributes and purposes of shared knowledge in teams (e.g., [18, 25]). Following Cannon-Bowers and Salas [28], I shall present 4 types of knowledge sharedness. These types are separated here only for didactical purposes. Naturally, in any given team all types can simultaneously operate.

(1) *Distributed knowledge* refers to situations where different members hold discrete pieces of information in an organized manner that exploits the team's mental resources. This knowledge is not concealed from other teammates. Rather it is divulged and actively considered [25] since it can be a source for expanding the team's available

Table 1: Knowledge Sharedness Categories, Functions, and Attributes

Sharedness Category	Function	Attribute
Private	Enable individuals to operate in interpersonal situations and to fulfill their roles in teams	Intrapsychic conscious and unconscious materials
Distributed	Ease information load	Discrete knowledge organized among team members
Complementary	Enlarge team's knowledge and abilities	Particular information that completes others' knowledge
Overlapping	Ease communication processes and coordination	Common knowledge among teammates as a subset of larger knowledge
Identical	Enhance cohesiveness but can cause group maladies	Matching knowledge among teammates

resources [124]. This is especially true in teams that are characterized by distinct roles allocation where members are required to possess unique information and to ease cognitive load. In those teams the knowledge is specialized and assigned across teammates, thus potentially allowing effective management of essential information and adequate coverage of vital knowledge.

The distributed knowledge category chiefly includes operator knowledge, and particular pieces of information that are essential for problem solving and decision making. Since one benefit of a team is to distribute and not to duplicate labor [26] having all members hold all or most of the available information is an inefficient use of group resources, particularly when information load is high [121]. In light of Wegner's [22] ideas, it can be suggested that the distribution of knowledge among members within the transactive memory system can reduce cognitive load, provide access to an extended pool of knowledge and expertise, and decrease redundancy of efforts [125]. Therefore, the distributed knowledge category is the one that most overtly implements teamwork benefits in allocating information, knowledge, and responsibilities to different team members.

(2) *Complementary knowledge* refers to knowledge that is compatible but not identical among teammates. Cooke *et al*. [48] stated that role specific yet compatible knowledge is required for handling teamwork's complexity. However, the literature concerning TMM has underemphasized the complementary perspective of shared knowledge [25]. Cannon-Bowers and Salas [28] pointed out that in holding complementary knowledge, team members can still draw similar expectations, without the need to share their knowledge. This case is of great significance in multidisciplinary teams and in teams with specialized role assignment. In those instances members have different areas of expertise or points of view, and unshared information is more frequent [121] thus the role of complementary knowledge is more salient.

Complementary knowledge can be viewed as a private case of a distributed knowledge that is organized in a complementary manner. The complementary effect assumes that the other's point of view is enriching and fertilizing and not a potential threat or a source for destructive conflicts. It is especially vital in heterogeneous teams where many contradictions can occur. In those teams, rising doubts and creating alternative ways of thinking are crucial for successful performance. Especially when members with different backgrounds are engaged in a constructive thought process, the diversity can lead to new and better ideas, and result in deeper learning, creative insights and solutions [34].

(3) *Overlapping knowledge* refers to common knowledge representation that usually evolves through frequent interactions between team members, either during regular team activity or during socialization, education, and training processes. During these successive encounters the transitory collective cognitions of team members are negotiated, and shared mental models are developed [123]. Langfield-Smith [123] stated that when individuals function as members of an organizational group there will be some degree of overlap in the content of those individuals' cognitive structures, while the specific degree of commonality may differ between group's members, thus forming different coalitions of shared knowledge.

The overlapping knowledge category does not imply that team members hold fully redundant information [28]. Rather, that they are expected to share some portions of their knowledge, but can also retain different knowledge structures that do not overlap with other members. However, especially in teams with distinct roles, overlapping knowledge may be inefficient, create redundancy of efforts, and contribute to a suboptimal utilization of resources [25]. Hence, in order to maximize teamwork effectiveness there must be an optimization of congruence between members' knowledge structures in a sense that their equivalence is kept at the minimum required level for task fulfillment.

(4) *Identical knowledge* refers to situations where team members hold similar knowledge structures. This category encompasses the cumulative knowledge that members hold as a result of their shared culture, social and organizational systems, indoctrination processes, and experiences. The function of identical knowledge is important in drawing common interpretations and expectations [28], and in gaining mutual perceptions and joint construction of the social reality. It can be a product, as well as an input, of great unity,

consensus, and cohesiveness in teams. On the other hand, in its extreme, identical knowledge can lead to poor team processes and outcomes [48], and can be held accountable for a number of maladies, such as groupthink and group polarization.

Identical knowledge plays a major role in creating the team's culture and in supporting newcomers upon their entrance to the group (Bettenhausen & Murnighan, 1985). Through socialization processes, one may undergo 'cognitive reconstruction' and acquire vital knowledge and orientation [123]. Note however that identical knowledge should not be considered as similar to organizational culture, which is a broader much stable notion that is less cognitive oriented [126]. There are obviously strong connections between the two concepts since organizational culture is characterized by shared meaning, understanding, and sense-making [127]. Actually, it was found that knowledge structures commonly held by top management teams have an important influence on the development of the organization culture and climate [126].

In sum, the previously presented categorization system implies that authors should explicitly declare what type of knowledge sharedness they explore and manipulate. Each knowledge category has its own advantages and weaknesses. Thus, future research should investigate the contingency between the team's situation (in terms of structural and environmental factors), the degree of knowledge similarity, and the different shared knowledge categories that are required for optimal team performance.

Maladies of Team Mental Models

Although the aforementioned knowledge sharedness can stimulate positive emotions towards other teammates, enhance trust, propensity, mutual attraction, and cohesion [9, 128], it can also be a source for major problems and dilemmas. Specifically, it is plausible that holding shared knowledge does not ultimately guarantee effective team processes; sometimes even the opposite. Ineffective sharedness conditions can be detrimental for the team, cause an under-utilization of its resources [37], and a deviation from normative models [129]. These biases can lead to what Cannon-Bowers *et al*. [12] referred to as too much of a good thing. For example, Stasser [130] found that knowledge that supports member's prior preferences becomes dominant and overtly articulated during group discussion. In turn, this knowledge becomes widely shared among group members. However, as consensus emerges group discussion may turn to be more distorted [121]. Therefore, groups might reach a point where the overlap in members' knowledge becomes a liability, with all members processing the same knowledge in the same manner, and the potential contribution of each individual is lost [12]. Under these circumstances the mental similarity among members results in a refusal to abandon incorrect views of the world [9].

Other evidences for ineffective knowledge sharedness can be found in the *solution-mindless*, where team members tend to agree on solution very early in the process (e.g., [131]), and in the related *groupthink* phenomenon (e.g., [132]). This phenomenon describes instances where members are extremely seeking to achieve concurrence and thus are inclined to poor decision-making process and outcomes, and to information processing pathology. Janis [132] postulated that groupthink is likely to occur in highly cohesive groups where the desire to achieve consensus and harmony inhibits systematic and coherent processes. Naturally, extensive knowledge sharedness can have an important influence on this process.

Other examples for excessive knowledge sharedness are manifested in the *group polarization* phenomena, where the position that is held by the majority is intensified as a result of discussion (e.g., [133, 134]); the *false consensus effect*, where members tend to overestimate the degree of similarity between self and others (e.g., [135]); and the *group non-rational escalation of commitment*, where members tend to support a course of action despite evidence that it is failing (e.g., [136]). These illustrations should be given special consideration when studying and implementing mental models mechanisms in teams, especially in instances that are characterized by intensified knowledge similarity.

IV. A THEORETICAL FRAMEWORK FOR TEAM MENTAL MODELS

The saying goes, there is nothing is more practical than a good theory, and Weaver *et al*. [13] noted that research is best directed in relation to a particular theoretical paradigm. Hence, the purpose of the current section is to integrate the ideas and conceptualizations presented thus far, and place them in a nomological network, which delineates TMM antecedents, processes, and consequences.

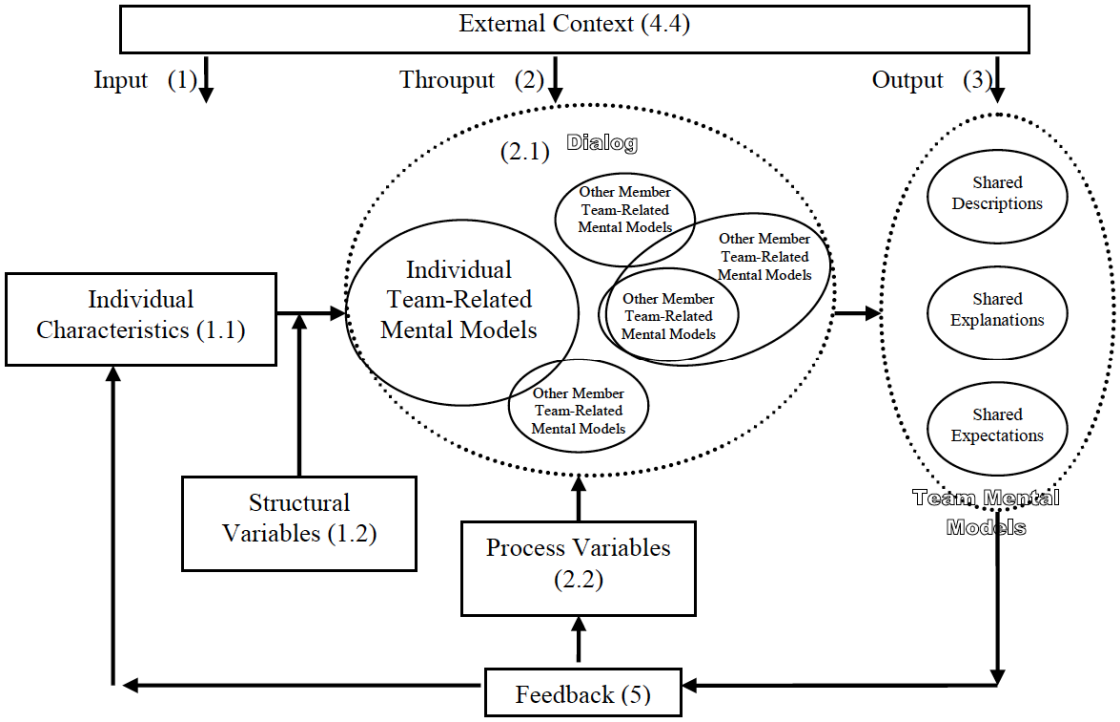

Figure 2: A Theoretical Framework of Team Mental Models. Antecedents, Processes, and Consequences.

Numerous theoretical models have been developed in an attempt to clarify team performance (e.g., [137, 138]). Researchers (e.g., [1]) acknowledged that no single model can encompass and deal simultaneously with the complexity of factors that can affect group task effectiveness. Instead, they suggested that we should settle for a number of more limited theories. Given this, the current theoretical model does not attempt to provide a global view on teamwork, rather to draw on specific aspects of TMM.

The model presented in Figure **2** was partially inspired by a number of traditional as well as contemporary team effectiveness models (e.g., [94, 139]), and is based upon the classic input-throughput-output model, which has a long history in small group theoretical conceptualizations (e.g., [1]). By formulating this model I wish to illustrate the relevant factors that are involved in TMM phenomenon, and delineate the ones that need further investigation or re-conceptualization. Following is a short description of each component in the model.

(1) *Input Variables* include individual characteristics and structural variables. This cluster of variables is rather stable and given to team members.

(1.1) *Individual characteristics* are considered to be a central antecedent in TMM since they encompass the entire individual potency for operating in teams. Examples of individual characteristics are personality variables (e.g., sociability, adjustment), demographic variables (e.g., age, socioeconomic background), knowledge, skills, and abilities (e.g., operating skills, knowledge about other teammates), dynamic situational variables (e.g., motivation, mood), physical variables (e.g., strength, height), cognition variables (e.g., mental complexity, degree of differentiation), attitudes, beliefs, values, and basic assumptions (e.g., a belief that the team is a source for comfort), and past experience (e.g., past roles in teams, past interpersonal relationships, past teammates, past successes and failures, past history with current team).

(1.2) *Structural variables* are also considered to be an important factor in TMM construction since they represent the boundaries within which the team operates. These variables are given to the team members and are usually beyond their control. Examples of team structural variables are communication structures (e.g., direct, technology mediated), task characteristics (e.g., complexity, type), degree of interdependency, team size, formal role assignment, team composition, reward system, and team rules of operation. Note that the structural variables are considered here as moderators that affect the

associations between the individual characteristics and the TMM.

(2) *Throughput variables* include dialog activities and process variables. This cluster of variables mediates the associations between the input and the output variables.

(2.1) *Dialog* is considered to be the essence of the development of TMM. Through dialog activities teammates can communicate their private knowledge and transform it into collective one. Negotiations of shared and idiosyncratic understandings in teams are important and commonsensical [84] since they allow members to confront with conflicting perspectives and oblige them to reconcile their different assumptions [140]. Examples of dialog activities are planning, feedback, debriefing, training sessions, and informal team interactions. During these activities members are able to negotiate their team-related models and various degrees of sharedness can evolve. Figure **2** depicts a dialog among a team of five members. It shows that while some portions of members' mental models are isolated, others are shared in various ways (e.g., complementary, overlapping, identical).

(2.2) *Process variables* develop as the team operates and give the team its unique nature. These variables affect the degree and quality of dialog activities that occur among team members. They are considered to be crucial in assessing the team effectiveness level (e.g., [77]) since they mediate the influence between input factors and performance outcomes (e.g., [141]). Examples of process variables are emotional tone that evolves in teams, degree of cohesiveness, team spirit and morale, amount of cooperation, communication, interpersonal relationships, and team norms.

(3) *Output variables* are not manifested here as team performance or other conventional outcome variables (e.g., member satisfaction), rather as direct consequences of negotiations among members' mental models. The scope of the current framework was intentionally narrowed in order to focus exclusively on TMM. In light of the previously mentioned core functions of TMM, the current model delineates *shared descriptions, explanations, and expectations*, concerning instrumental and socioemotional behaviors in teams, as the output variables. By specifying TMM outputs in this manner, I follow Paris *et al*. [8] that urged authors to develop better specified models, which can more precisely guide measurement and training efforts. Rouse *et al*. [27] also maintained that concentrating on underlying mechanisms rather than on global behaviors may enable the development of a finer-grained understanding of team-related phenomena. Nonetheless, the "bottom line" of team performance is of ultimate importance and effective mental models are to be assessed in light of their contribution to team effectiveness [15].

(4) *External context* is the final influential factor in the process of constructing TMM since teams rarely operate in a vacuum. Relevant contextual factors originate outside the team but influence its environment. Examples of context variables are global culture (e.g., collectivism vs. individualism), organizational characteristics (e.g., degree of ambiguity, complexity, organizational culture, managerial style), and situational variables (e.g., physical environment, technology). Team training and other forms of education and indoctrination processes are also located as external factors.

(5) *Feedback* loops are continuous processes that take place in teams and affect the evolvement of TMM. During these processes, the shared mental products of team members are evaluated and reexamined. The products of these feedback processes are then introduced as influential factors both to the team processes and dialogs, and to the individual. They can modify the degree of sharedness during the dialog, as well as be assimilated in the individual accumulated team experience.

Observing the presented theoretical framework, several comments ought to be made with respect to future research. First, given the proposed central role of individual characteristics in the formation processes of TMM, it is suggested that insufficient research efforts are being dedicated to delineate the personal factors that contribute to the establishment of well articulated and effective team-related mental models. Second, the proposed effects of external context and structural variables are also not given sufficient research attention. Specifically, if we accept the notion that the

functionality of TMM is manifested in team members' ability to be flexible in light of changing demands then we should examine mental models' adjustment to these circumstances more carefully. Exploring the flexibility that effective TMM provide can be considered as a vital route in future research given the growing complexity of the organizational environment. Third, a better understanding of the dialog and the process variables that play a meaningful role in converting personal knowledge into communal one is required. These efforts are particularly relevant to team training programs. Finally, the dynamic nature of TMM should be better appreciated through a profound inquiry of modification processes that occur in light of external and internal feedback.

V. EMPIRICAL FINDINGS OF TEAM MENTAL MODELS

Although the term team mental model is fairly intuitive and widely used, its empirical measurement is complex, problematic, and has lagged behind descriptive and theoretical work [9]. Carley [142] argued that while there is a general agreement that it would be useful and important to examine mental models, there is little understanding as to how to uncover, derive, code, or analyze such models. Cańas *et al*. [60] posited that mental models' methodological problems exist, in part, due to definition problems, and that despite numerous methods that have been proposed, all have been criticized as being unreliable.

One of the central problems in the empirical study of TMM is the diversity of methods and the disintegration of findings and conclusions. It appears that researches' conclusions tend to derive from the chosen method, and in some cases the measuring method restricts and even determines the type of data collected [58]. The notion that different methods elicit different types of knowledge has been labeled as the differential access hypothesis [143]. In the current stage of research evolution in the TMM domain this has become a major problem in advancing our knowledge. Therefore, the purpose of the present section is to review the empirical work conducted thus far, and to integrate the major findings in order to provide a systematic and coherent view.

Early Empirical Indications

Although I mentioned before that most empirical work has been conducted from the onset of the 1990s, direct and indirect experimental attempts can be found as early as the 1950s. For example, back in 1952 Hemphill and Rush [144] suggested that sharing knowledge concerning functions and role responsibilities can enhance team performance [12]. Upon exploring conflict resolution, which derives from cognitive differences, Hammond [145] concluded that members of ineffective teams utilize stimulus cues differently as a function of divergent mental representations of the task. Brehmer [146] presented a more direct evidence for shared mental models concerning policy conflict, and demonstrated a relation between subjects' policy similarity and agreement in conflict situations.

Subsequently, researchers tapped into the issue of shared cognitive maps, and suggested that these knowledge structures are available for sharing among group members (e.g., [147-149]). This argument gained some support. For instance, Athens [150] found that through team training each military commander develops a mental picture that represents an aggregated version of the tactical decision making process of his fellow commanders. Prahalad and Bettis [151] found that mental maps that evolve in top management become the "dominant general management logic". In turn, this logic has a significant influence on the way the firm is managed. Bennett and Cropper [152] demonstrated that blending cognitive maps of government planners induced several common elements that lay beneath the surface of a conflict in their work place.

Researchers have also delineated the role of shared knowledge structures during norm formation and common beliefs creation in groups. To illustrate, Calder and Schurr [153] found that groups can develop particular knowledge structures in their new members upon their entrance to the group. Bettenhausen and Murnighan [117] demonstrated that members utilize scripts for generating behaviors and that these scripts are either taken for granted or negotiated within the group to induce common group behaviors. Walsh and Fahey [154] acknowledged that each group member's knowledge structure represents a fundamental element in the group's collective knowledge structure. They hypothesized that upon commingling of power and beliefs, strategic decision making groups will yield negotiated belief structures, which in turn will affect strategy making and implementation in predictable ways.

Finally, researchers have explored the issue of knowledge overlap in groups. For examples, Adelman *et al*. [141], upon manipulating the degree of overlap in

members' knowledge, demonstrated several modifications in team's performance. Walsh *et al*. [99] argued that although each member's mental structure varies in the number of dimensions that are represented in it, an additive aggregation can potentially supply coverage for the information domain. These authors argued that members who participate actively in group decision-making process are likely to contribute to the group's collective knowledge structure, while the degree of sharedness between members' schemas represents consensus. Stasser and Titus [155] found that groups often fail to effectively pool their information because discussion tends to be dominant by information that members hold in common before discussion. Unshared information tends to be omitted from discussion and have little effect during group discussion.

Looking at the previously mentioned empirical studies, it can be concluded that although some earlier studies measured cognitive structures and mechanisms, their work did not directly explore TMM construct and did not fully utilize its conceptual potency. Indeed, Klimoski and Mohammed [9] and Mohammed *et al*. [91] argued that only a small amount of relevant empirical research in the TMM domain can be found in the literature, most of which is indirect and merely suggestive, with the concept of TMM often invoked post hoc to help describe and interpret team phenomena.

Contemporary Empirical Indications

By the onset of the 1990s, researchers had several empirical indications and intuitive conceptualizations that teams draw upon their members' mental resources to advance their performance. From this point on a growing flow of studies can be traced that explicitly employed TMM as an explanatory factor that captures elusive aspects of teamwork behaviors. Particularly, these studies explored teams in real-time tasks where the effects of TMM are most exemplified [59]. In the present section I shall review these studies, while concentrating on those that were conducted from 1990.

Empirical studies in the TMM domain explored team processes and outcomes using various techniques and methodologies, such as: verbal protocol analysis, card sorting, repertory grids, casual maps, content analysis, and task observation (for a methodological review see [48]). Although most studies were conducted in command and control or military teams [11], empirical evidence can also be traced in top management and strategic teams, decision making teams, problem solving teams, and other organizational work teams. Research is also being conducted in laboratory teams, while focusing on measurement techniques, training, team dynamics, and individual differences.

Cooke *et al*. [48] argued that measures of team knowledge should be developed, applied, and evaluated in the context of the targeted team. Thus, although there are numerous types of teams, which vary in functions, nature, and relationship [129], I shall concentrate on contemporary empirical findings driven from 4 different team types: laboratory teams, organic work teams, decision making teams, and command and control teams. In the current review I tried not to replicate previous reviews (e.g., [12]; [9]; [87]), but to provide the state-of-the-art findings. Also, a number of studies are not included in the current section since they were discussed in previous sections of this paper. Finally, this review does not provide a calculation of mean effect size since this data was recently reported by Griepentrog and Fleming [156].

Laboratory Teams

Traditionally, laboratory research of teamwork has been widely used but also widely criticized. Bowers, Salas, Prince, and Brannick [157] indicated that laboratory team investigations range from artificial and contrived tasks to complex and expensive high-fidelity simulations. For example, Gruenfeld and Hollingshead [47] had participants in a workshop study write weekly essays about their group activities. Members wrote independent and collaborated essays. They found that the groups' essays were not mere combinations of the individuals' essays; rather, they were characterized by higher levels of differentiation and integration. In addition, the integrative complexity in the group essays increased over time. In a similar vein, Bangerter [158] explored the process of interpersonal continuity in groups. He performed a complex computer simulation of group activity and demonstrated that members create shared knowledge in the course of their interactions. He found that redistribution processes, through which members create similar knowledge structures, take place mainly at the outset of meetings. In addition, he found that members with different knowledge structures participated differently in these redistribution processes.

Given this central role of individual knowledge structures during teamwork, a number of researchers directly explored TMM from an individualistic perspective. For example, carley [142] instructed small project teams to analyze client's needs, and to design

and build an information system to meet those needs. She found that on average the cognitive maps of members of successful teams tended to be more elaborated, larger, and with higher degrees of sharing then unsuccessful teams. Similar results were obtained by Rentsch *et al*. [32], who evaluated teamwork schema through multidimensional scaling and freehand concept maps. They found that higher experienced members conceptualized teamwork more concisely, consistently, and abstractly than low experienced ones. The role of experience in the formation of TMM was also explored by Smith-Jentsch *et al*. [6]. These authors investigated the effects of rank and length of time in service on TMM held by naval personnel. They found that higher-ranking individuals held mental models that were more similar to an expert model, hence were more accurate. In addition, they found greater similarities in mental models held by higher ranks and greater experienced individuals. Subsequently, they tested the effectiveness of a computer-based training tool designed to guide individuals in adopting the expert model of teamwork, and found some positive training effects, including consistency and similarity to the expert model and to other trainees.

Liang, Moreland, and Argote [159] also explored training effects on TMM formation. These authors tested performance differences in teams that their members were trained separately or collectively. Based upon Wegner's [22] notion of transactive memory, they demonstrated that team performance can indeed be improved by training members together rather than separately. Subsequently, Moreland and Myaskovsky [160] challenged Liang *et al*. [159] conclusions and argued that the performance benefits associated with collective training are due to improved communication that develops among members and not a result of transactive memory effects. These authors found that teams in which members were trained apart performed well after receiving information about one another's skills, and reached the performance level of the teams in which members were trained together.

Organic Work Teams

In this category I include studies that were conducted on natural organizational settings. For example, Earley and Mosakowski [114] investigated the creation of team culture in a large multinational clothing company. They found marked differences between teams with different levels of cultural heterogeneity. Over time, however, the teams created a hybrid team culture and a common identity that facilitated their understanding, coordination, and communication.

A number of studies explored the formation of task oriented TMM in organic work teams. For example, Espinosa *et al*. [161], conducted a field study in two separate divisions at a large international telecommunication company. They found that TMM help coordination among software development teams and that prior familiarity with the same software parts and projects reduces software development time. However, upon exploring the development of TMM in software development teams, Levesque *et al*. [109] could not find any increasing similarity among members' models over time. Actually, TMM became dissimilar over the course of the software development project as roles became increasingly specialized and interaction opportunities declined. Smith and Dowell [79] investigated the role of shared mental models in a multi-agency response to a railway accident in the UK. These authors regarded the management system as a special kind of team in the sense that they share common goals and distinct roles, although they may not have worked together prior to the accident. They maintained that coordination difficulties that were observed during the disaster management were associated with weak TMM of the decision making process and its participants. As a consequence, the formation of task-oriented TMM was also inhibited, and the potential use of available rescue resources was not effectively disseminated.

Aside from exploring task oriented TMM, researchers have also tested effects of shared beliefs among organic team members. For example, Gibson [93] conducted a field study among nursing teams in Indonesia and United States hospitals. She found that a mutual belief within a team regarding its effectiveness (i.e., team efficacy) is not always an asset. Specifically, the nature of relationships between team efficacy and effectiveness was associated with the specific type of task and the cultural context in which the team was embedded. Edmondson [92] studied real work teams in a manufacturing company. She found that shared beliefs among team members, concerning the perception of the team as being a safe place for interpersonal risk taking, was positively associated with learning behavior, which in turn affected team performance. Cannon and Edmondson [34] performed a field study in a mid-sized manufacturing company. They found that teams in the same organization, even those doing similar tasks, vary substantially in their

beliefs about failure. In turn, these shared beliefs were associated with team performance. In addition, they demonstrated that the ability of team leaders to provide effective coaching, together with the presence of a clear direction, facilitated the development of these constructive shared beliefs.

Indeed, the role that team leaders and management teams fulfill in TMM development has attracted a number of authors. For example, Cohen, Mohrman, and Mohrman [162] found that contextual and process direction-sharing positively contribute to a development of shared understanding of priorities and work to be done, and contribute to team effectiveness. Ensley and Pearce [43] explored top management teams and found that engaging in cognitive discussion of the elements of organizational strategy can positively impact shared understanding. Although they could not establish a linkage between shared strategic cognition and organizational performance, they concluded that the process of developing shared cognition is more important than the specific components of that cognition once it is formed.

Decision Making Teams

The process of team decision making relies on running mental models [26], and can be characterized as negotiation of common constructs [163]. A number of studies investigated the role of TMM during team decision making, although some of them merely tapped into the issue of knowledge sharedness. For example, Larson *et al*. [124] examined impacts of knowledge sharedness, in light of Stasser and Titus's [121, 155] information sampling model. They demonstrated that groups discussed much more of their shared information than their unshared information, although pooling unshared information improved the team effectiveness. Langfield-Smith [123] also explored knowledge sharedness during team decision making. However, in her experiment she could not elicit collective maps using a structured protocol. She then concluded that members do not necessarily need to share an extensive system of beliefs. However, she acknowledged that these beliefs do exist, but perhaps are more readable in cohesive teams and as the task progresses.

Some support for these claims was found by Espinosa and Carley [59] that performed a management simulation during which teams competed against each other by formulating strategies based on multidisciplinary decisions. They found that TMM concerning the task strengthened as task progresses, whereas TMM concerning social issues did not demonstrated such a significant steady increase. Also, TMM were positively associated with communication frequency, task coordination, and task knowledge overlap. However, in respect to knowledge overlap, Banks and Millward [26] found that the organization of knowledge among members is more crucial than the degree of overlap. Specifically, they found that teams with organized distributed knowledge were able to reach a solution with less information then teams with completely overlapping knowledge.

Another aspect that influences mental similarity among team members, aside from knowledge sharedness, is the team decision rule. Mohammed and Ringseis [140] found that unanimity decision rule teams achieved more cognitive consensus (i.e., similarity regarding the conceptualization of key issues) than majority rule teams. In their multi-issue decision making exercise they showed that cognitive consensus was positively related to several team process variables (e.g., accepting others' viewpoints as legitimate), and to expectations regarding decision implementation and satisfaction.

Finally, TMM during team decision making was also explored in the context of training. For example, Cannon-Bowers, Salas, Blickensderfer, and Bowers [164] replicated and extended Volpe *et al*. [101] findings concerning impacts of cross-training. Building on Volpe's findings that cross-training improved teamwork processes and outcomes, these authors had teams engage in a decision making task that simulated decision processes in Combat Information Center of ships. They found that cross-trained teams developed a greater degree of interpositional knowledge that allowed them to coordinate implicitly and facilitated the formation of TMM. Mumford, Feldman, Hein, and Nagao [165] have also used training to provide teams with shared mental models. They demonstrated that availability of a large number of diverse alternative solutions tended to disrupt team functioning, whereas having a limited number of high quality alternative solutions enhanced performance. They suggested that teams refine and extend the limited alternatives to generate solutions, and that this process is based upon attaining appropriate TMM.

Command-and-Control Teams

In this category I include teams with tasks that are strictly organized, complex, and characterized by rapidly changing situations with limited time available. Examples of command and control teams include

military units, fire-fighting teams, emergency medical teams, and cockpit crews [129]. Members in those teams have information dependency among them, their roles are clearly differentiated, and coordinated patterns of interdependence are specified and highly structured [12, 53]. In those teams the role of effective TMM is most prominent. To illustrate, Orasanu [95] found that copilots in effective aircrews, upon encountering high-workload conditions, increased the amount of information they provided in advance, whereas pilots decreased the number of requests for information. Less effective teams showed the reverse pattern.

Researchers who wished to explore the role of TMM in command-and-control teams often utilize simulation systems. For example, Minionis [166] conducted a tank simulator and found that shared mental models significantly enhanced coordinated performance. In addition, he found that teams that trained in a cooperative learning environment were better able to cope with adverse effects of battle stress. Rasker *et al*. [53] assembled command-and-control teams that played an interactive computer game in the form of a fire-fighting task. They found that communication between team members allowed intra-team feedback that fostered the development of shared mental models, which in turn improved team performance. However, these authors demonstrated that teams that had the opportunity to engage in performance monitoring (i.e., give feedback during task execution) performed better than those that had the opportunity to engage in team self-correction (i.e., give feedback after task execution). Stout *et al*. [82] demonstrated that mental models' sharedness, in teams that performed a flight simulator task, enhanced communication under high workload and improved coordination and performance. They found that high-quality planning helped members to form greater shared mental models of each other's needs and informational requirements and facilitated their abilities to provide information in advance, to make fewer errors, and to perform better. Mathieu *et al*. [11] also studied the influence of shared mental models during a flight-combat simulation. They found that mental sharedness was positively related to subsequent team process and performance. Furthermore, these authors demonstrated that team processes fully mediated the relationship between mental models sharedness and team effectiveness. Cooke *et al*. [35] performed a study among Air Force cadets in the context of a synthetic 3-person team task, based on the real task of controlling an uninhabited air vehicle. They found that teams reached asymptotic performance that was paralleled by improvements in team situation models, teamwork knowledge, and team process behaviors. In addition, high performing teams had more knowledge of the task from the perspective of other team members, than lower performing ones. Marks, Sabella, Burke, and Zaccaro [167] had students in three-person teams play a flight simulator. They investigated the effects of cross training in developing shared team-interaction mental models, and found that cross training enhanced the development of TMM, and that coordination mediated the relationship between TMM and team performance.

Given this central role of team training, a number of studies explored this issue in flight teams and in other command-and-control teams. For example, Stout, Salas, and Kraiger [168] trained pilots on introductory concepts related to teamwork and on specific teamwork skills. They found that aviation team training improved the knowledge structures of trainees in the sense that they became more similar to an expert referent and more internally consistent. In addition, these modifications in knowledge structures were consistent with performance results of those teams. Stout, Cannon-Bowers, Salas, and Morgan [169] performed a field study of military training in command-and-control teams. They found that high-performing teams tended to receive high coordination scores, and that the vast majority of team performance deficiencies observed were associated with inadequate, inappropriate, or a lack of shared expectations and explanations. Entin and Serfaty [81] also tested effects of team-training. They found that the training significantly improved team processes and performance and enhanced implicit coordination. The effective coordination strategies, which were implemented by the experiment teams, involved the usage of TMM.

SUMMARY AND INTEGRATION

Mental models were initially offered as knowledge structures that humans use to organize new information, describe, explain, and predict future events [36]. These cognitive representations were also proposed as internal mechanisms that guide social interaction with others [128]. In the team context, it was postulated that mental models allow members to implicitly synchronize their behaviors. Through a holding of effective team-related mental models, members are able to recognize individual responsibilities and information needs, monitor their activities, diagnose deficiencies, and provide support,

guidance, and information as needed [8]. Various authors suggested that shared cognition among team members will lead to better task performance, team processes, organizational outcomes, and positive attitudes [28]. Nevertheless, thus far there has been minimal empirical work to support these claims [48]. Moreover, the TMM discipline is currently characterized by lack of interdisciplinary communication, which leads to disintegration and incoherence [18].

The ideas and findings presented in the current article indicate that TMM can capture several team-related phenomena in a constructive manner, although further empirical exploration is definitely in order. Despite a number of limitations, after more than a decade of TMM research, it can be argued with a decent degree of certainty, that there is indeed a positive relationship between TMM and team performance.

Taken as a whole, the previously presented empirical studies provide substantial support for the TMM theory, although the results and the magnitude of effects are not sufficiently consistent. While utilizing a wide array of methodologies and exploring teams in diverse settings, a fairly sound pattern emerges which points to a positive association between TMM and team performance. Griepentrog and Fleming [156], who recently performed a meta-analysis, calculated a corrected mean effect size of .31 for this general relationship, and thus offer additional support for this claim.

Integrating the findings accumulated thus far indicate that holding adequately shared mental models increases coordination among team members, improves communication processes, and enhances team performance in terms of time and quality. These positive outcomes are most exemplified in teams operating under high workloads. In addition, developing effective mental models in teams is associated with an establishment of a collective identity, mutual understanding, and well-synchronized behavior. These products are manifested in taking the perspective of the other person, anticipating his or her needs and requirements, and enrolling in proactive behaviors (e.g., providing information in advance), thus reducing functioning errors.

The studies that were reviewed in the current paper indicate that successful teams are characterized by well organized and effectively distributed knowledge structures, and not necessarily by knowledge overlap or similarity. Members in those teams tend to hold well-articulated, elaborated, multifaceted, abstract and concise mental models and require less information in order to achieve high levels of performance. The research demonstrates that previous experience in teams, particular forms of team training, planning activities, intra-team feedback, supportive climate, common cultural context, effective leadership and coaching, presence of a clear direction, spending time together, and engaging in discussion activities facilitates the evolvement of valid, consistent, and commonly held mental models.

Given these potential benefits, it seems that further inquiry in the domain of TMM is a promising research avenue to pursue. Although research on TMM is in its infancy [25], the passing decade has supplied substantial empirical evidence as well as profound theoretical conceptualization. The current paper offers an integration and organization of this knowledge in hope to supply ‘shared mental models’ among researchers that will allow us to reach a better understanding of teamwork effectiveness.

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