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The role of leadership in shared mental model convergence and team performance improvement: An agent-based computational model

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ABSTRACT

Research in shared mental models has immeasurably aided our understanding of effective teamwork and taskwork. However, little research has focused on the role that leaders play, if any, in influencing, developing and/or fostering shared mental models and thereby improving team performance. We developed an agent-based computational model based on McComb's theory of three-phase mental model development, where agents repeatedly share individual opinions (orientation phase), evaluate and respond to the opinions expressed by others (differentiation phase), and modify their understanding of the team based on the responses (integration phase). Leadership and team properties are represented in three experimental parameters: social network structure, heterogeneity of agents' domains of expertise, and level of their mutual interest. Participative leadership is represented by a fully connected network, while Leader–Member eXchange (LMX) is represented by a fully connected network of in-group members and several out-group members connected only to the leader. Our simulation results show that, in general, participative leadership promotes mental model convergence better than LMX. In the meantime, the team performance improvement is achieved by participative leadership only when members have both heterogeneous domains of expertise and strong mutual interest. In all other conditions, participative leadership causes the worst degradation of team performance through team development processes, while LMX is the best to minimize such team degradation. Implications and suggestions for future research are provided.

Recent research links shared mental models to improved team performance (Marks, Sabella, Burke, & Zaccaro, 2002; Marks, Zaccaro, & Mathieu, 2000; Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000; Smith-Jentsch, Mathieu, & Kraiger, 2005), and also leadership to team performance (Bell & Kozlowski, 2002; Keller, 2006; Kozlowski, Gully, McHugh, Salas, & Cannon-Bowers, 1996; Kozlowski et al., 1996). However, little research exists exploring the intersection of these two areas: leadership and its potential impact on development of a shared team mental model and subsequent team performance. Although purely self-led teams exist, a more realistic scenario is that teams operate in a semi-autonomous environment (Manz & Sims, 1987; Zaccaro, Rittman, & Marks, 2001). In other words, even if there is no internally specified leader, there is generally an external leader managing or responsible for the productivity and/or decisions of the team (Morgeson, 2005; Yukl, 2002). As such, this intersection

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could be an important contribution regarding improved team performance and understanding of how leaders may influence a team's mental model convergence.

Recent work on mental model convergence highlights three key phases within the process: orientation, differentiation and integration (McComb, 2007). As these phases involve activities such as information acquisition, exchange, organization, and assimilation as well as reconciliation of perspectives within the team, a leader's influence and perspective may play a key role within this information elaboration process. More often than not, leaders are a key portal for information and resources, and therefore likely involved by virtue of their position in the information elaboration process.

Additionally, as convergence unfolds through an emergence process (Kozlowski & Klein, 2000; McComb, 2007), factors related to emergence such as combination of team efforts and interaction dynamics also may be subject to a leader's influence. Going a step further, interaction dynamics may be influenced by social network structures, which can represent a key process by which leaders operate, and may affect a leader's ability to perceive and interpret characteristics of the team (Balkundi & Kilduff, 2005). Thus, potential exists for leaders to affect both mental model convergence and team interaction processes which have been related to convergence.

As groups likely interact dynamically, interdependently and adaptively (Salas, Guthrie, Wilson-Donnelly, Priest, & Burke, 2005), consideration of leadership's role in the convergence of team mental models is likely a dynamic and multi-level phenomena as well. Besides considering levels of analysis issues in an emergent process that unfolds within a team, levels of analysis issues related to team leadership need to be addressed as well. Also, social network structures may be different under various leader conditions and as such present another layer of complexity in examining leadership and team mental model development. Thus, the challenges involved in this type of research are apparent. However, as teams continue to be a primary source of complex problem solving in organizations (Manz & Sims, 1987), an urgent need exists to improve understanding related to a leader's contribution to convergence of mental models and ultimately improved team performance.

Thus, the focus of this paper will not be a review of current literature as traditionally expected in an annual review issue, but rather a promotion of the importance of considering leadership and leadership processes where they have not traditionally been considered before—team mental model convergence. We begin with a review of mental model convergence, and then highlight the role emergence, leadership and social networking may play in both mental model convergence and team performance. Specifically, we examine emergence in either a homogeneous or heterogeneous setting while altering the leadership within the team to reflect varying degrees of low- and high-quality leader member relations as well as a more egalitarian, shared leadership. The social networks reflected in these various forms of leadership are highlighted to determine their impact on mental model convergence and early team decision performance.

As the above focus reflects a dynamic leadership and team process, we develop an agent-based computational model to examine theoretical assertions regarding the complex and level-specific relationships between leadership and mental model convergence and team performance. Agent-based modeling has the inherent benefit of being able to capture dynamic, multi-level and complex relationships within teams unfolding over time (Dionne & Dionne, 2008; Kerr & Tindale, 2004). Therefore, within a levels-specific view of emergence and leadership, we use social network structure as the basis for simulation and examination of team mental model convergence and performance.

1. Convergence

Convergence describes the bottom-up process experienced by teams beginning with the onset of team formation and continuing over the life of the team (Hill & Levenhagen, 1995; McComb, 2007; Rentsch & Woehr, 2004). Convergence represents a cognitive process where the emphasis (and level of analysis) shifts from individual team members–processing information independently–to the team, where shared and similar understandings guide collective information processing. Cumulative evidence supports converged mental models positively influence team functioning and performance (cf., Baba et al., 2004; Edwards, Day, Arthur, & Bell, 2006; Kang, Yang, & Rowley, 2006; Marks et al., 2000, 2002; Mathieu et al., 2000; Mathieu, Heffner, Goodwin, Cannon-Bowers, & Salas, 2005; Webber, Chen, Payne, Marsh, & Zaccaro, 2000). More specifically, the existence of shared mental models may assist team members to recognize one another's needs and information requirements (Stout, Cannon-Bowers, Salas, & Milanovich, 1999) and facilitate team communication (Entin & Serfaty, 1999).

Teams with high-quality mental models are more likely to exhibit better team processes and higher performance (Mathieu et al., 2005). More recently, DeChurch and Mesmer-Magnus (2010) conducted a meta-analysis to cumulate 23 empirical studies linking shared team mental models to team process and team performance. Consistent with prior research, results support that mental models are positively related to team performance. These empirical advances provide motivation for examining the process within mental model convergence, as several studies link to team performance but not necessarily address the underlying process and/or the levels of analysis issues involved in convergence.

McComb (2007) highlights a three phase process of mental model convergence recognizing this shift in focal level of interest (i.e., individual to team). The orientation phase is represented by an information dissemination practice across all members (McNeese, 2000). Information within this phase can be disseminated verbally, especially in situations where members may be familiar with one another or at least one another's expertise (Borgatti & Cross, 2003), or occur through observation, experimentation and inquiry, especially in cases where members may not be familiar with other members (Ostroff & Kozlowski, 1992). Although information may be missing from individual mental models in this phase, the expected outcome is to create a comprehensive understanding of the team's situation (McComb, 2007) at the individual level of analysis.

The differentiation phase occurs when comprehensive understanding of the team's situation or existing knowledge is merged with information related to each member and organized in such a way as to form each individual's mental model (McComb, 2007). The focal level of analysis remains individual as this phase represents each member's understanding of the perspectives of other team members. However, these perspectives are merely identified at this point and have not been integrated.

The final stage, integration, occurs when the team merges the various individual perspectives developed in the differentiation phase (Gruenfeld & Hollingshead, 1993). Arguably this may be the most difficult stage, as the level of analysis shifts from individual to team, meaning self-interest must be set aside to enable the development and health of the collective (i.e., team). McComb (2007) notes successful integration may take two forms, shared, where there is some level of detail commonly held across members, or divided, where knowledge is distributed across members.

As the integration phase may result in at least two forms, shared or divided, and represents the critical phase where convergence occurs, a more detailed view of the underlying emergence process may inform our understanding of convergence to shared mental models. Kozlowski and Klein (2000) present a multi-level view of emergence that may supplement our understanding of integration.

2. Emergence

According to Kozlowski and Klein (2000), emergence is where the collective constructs represent aggregate influences of individuals, and can take several forms. Two particular forms relevant to mental model convergence may be composition and compilation. Composition, analogous to McComb's (2007) "to share" model, is based on the notion of isomorphism where the interaction process and dynamics are focused on convergence and sharing. As such, the shared phenomena are represented through a linear procedure yielding a convergence point for the team (Kozlowski & Klein, 2000).

A theoretical assumption of isomorphism can be represented as a homogenous view of the team. This homogenous view of teams represents one potential view at the group level of analysis (Dionne & Dionne, 2008; Yammarino et al., 2009). The homogeneity factor present in composition forms of emergence is consistent with a "wholes" view of teams as discussed by Dansereau, Yammarino and colleagues (Dansereau, Alutto, & Yammarino, 1984; Dansereau & Yammarino, 1998; Dansereau, Yammarino, & Kohles, 1999; Yammarino & Dansereau, 2002) where the relevant entity of interest (i.e., groups) is between groups, and differences within groups would be considered error.

Compilation is analogous to McComb's (2007) "to divide" model, and is uniquely different from the composition model. Here, team members have a complementary focus where the different contribution capability of the team is understood to be distributed among team members. Patterns or linkages that connect individual performance are the emergent representation of interest and represent a discontinuous view.

Although variability and pattern are central to compilation, there remains a collective focus within the mental model that values diverse elemental content. Therefore, the focal level of interest remains the team (Dionne & Dionne, 2008; Yammarino et al., 2009); however compilation is better represented by what Dansereau and Yammarino and colleagues (Dansereau & Yammarino, 1998; Dansereau et al., 1984, 1999; Yammarino & Dansereau, 2002) refer to as group "parts." In this unique within-level view (i.e., group), the relevant entity of interest is within groups, and differences between groups would be considered error.

Given that there are at least two forms of emergence in which integration can occur, could leadership play any role in convergence? In reviewing the convergence process, Cannon-Bowers (2007) notes it "can be conscious and volitional, but it probably isn't in many cases" (pg. 150). She offers several training strategies designed to increase the awareness of convergence and the motivation behind convergence in an effort to enhance/exert control over the process. Although not specifically intended for leaders, the notion that increased awareness and motivation may assist the convergence process is highly relevant. As converged mental models have been linked to higher team performance (Mathieu et al., 2000), leaders that positively influence the convergence process may bring teams to higher performance levels. However, would merely any form of leadership improve or speed the convergence process, or are there likely some styles that are better suited to affect this process? The following section on leadership begins to explore these questions.

3. Leadership

In examining leadership related to convergence of mental models we were particularly interested in leader actions and behaviors consistent with leading within a group setting and highlighting leader–follower interactions as a key aspect of the theory. Moreover, given the above discussion regarding levels of analysis and emergent forms, leadership theories with clear levels of analysis delineations would further enhance our potential linkages. Therefore, we selected leader–member exchange (LMX) and participative leadership as a means for examining the influence of leader actions on mental model convergence. Both models have been linked to teams research in the past, consider leader–follower interactions and have a specific relevance for the group level of analysis (Dionne & Dionne, 2008).

3.1. Leader–member exchange

Leader–member exchange theory evolves as an exchange process whereby subordinates may have high-quality exchanges or low-quality exchanges (Graen & Uhl-Bien, 1995). High-quality exchanges are typified by increased effort and personal loyalty to the leader and in exchange, leaders allow these followers more control and influence (Graen & Uhl-Bien, 1995; Schriesheim, Castro, Zhou, & Yammarino, 2001). Moreover, leaders may view followers with high-quality exchanges as the “in-group” or “advisors” and treat the group in a similar fashion, attributing importance to these followers as a subgroup.

Low-quality exchanges are typified by followers who produce efforts that do not exceed expectations and rely on organizational exchange patterns to guide interactions. As such, leaders in low-quality exchanges are less likely to initiate or provide additional benefits (Graen & Uhl-Bien, 1995; Schriesheim et al., 2001). Leaders also may view this subgroup as an “out-group” with less importance than the “in-group” and as such, attribute less value to member input received from the out-group.

Because of the unequal emphasis given to subgroups, LMX leadership can be viewed at the dyad-within-group level of analysis (Dionne & Dionne, 2008; Schriesheim et al., 2001). Concerning team convergence of mental models, as the process moves from individual to group, a leadership style emphasizing select subgroups over other subgroups may be detrimental to the convergence process. Specifically, within the composition form of emergence, LMX may inhibit the progress from individual level of analysis to team level of analysis in that the dyad-within-group focus of the leader stalls the movement to group level of analysis. Moreover, the unequal emphasis on resource and benefits acquisition between the in-group and the out-group is likely to affect all phases of the convergence process.

3.2. Participative leadership

Participative leadership embodies joint decision making and shared influence among followers (Koopman & Wierdsma, 1998). Much of the research surrounding participative leadership and group decision making views leadership as generally homogenous within a group (Somech, 2003), and often assumes uniformity in leader behavior towards all members of a group (Vecchio, 1982). This between-group level of analysis leadership is likely to emphasize each team member as equally important, which could be a strong facilitator in promoting team mental model convergence.

Among a homogenous team, participative leadership providing equal emphasis to all team members is likely to promote balanced information dissemination (i.e., orientation), merging of knowledge (i.e., differentiation) and integration to produce a strongly shared team mental model. The group level of analysis of both participative leadership and integration are likely to be aligned more easily because of the consistent levels-based focus.

Among a heterogeneous team, where members bring differing and various expertise to a team, focus on participative leadership may promote interactions between experts that normally have no cause to interact. Consider that some team members have unique expertise unrelated to other members' expertise and view problems from a different perspective than other members. A participative leader emphasizing the importance of all member contributions may be the impetus a team needs to develop strong orientation and differentiation information exchange processes. These processes are believed to be key phases in the convergence process, and as such, participative leadership is likely to benefit mental model convergence.

4. Social network structure

Although more recent research has espoused that higher quality LMX relations with all members of a group may support better exchanges between subordinates (Graen & Uhl-Bien, 1995), produce lower levels of team conflict (Boies & Howell, 2006), and/or enhance team development (Sherony & Green, 2002), these views place primary importance on the benefit related to establishment of a dyadic, one-to-one, high quality relationship between leader and follower. Conversely, participative leadership is a purposeful action to encourage all members to treat each others as equal. This type of participative, egalitarian model is easily depicted as a fully connected social network, whereas LXM models of leadership may need to be represented differently due to the explicit leader–follower dyadic focus, even in the ideal condition where every member has a high quality relationship with the leader. Due to the different nature of each leadership model, social network structures may be very different within teams. And, as information elaboration is a key element within convergence, the way in which elaboration occurs through social networks may be a critical factor in understanding the role leadership plays in emergent team forms.

Recent research relating social network theory and leadership may have particular significance for better understanding leaders' roles in converging team mental models. Although much of social network theory regarding leadership focuses on multiple levels, including organizational and inter-organizational networks, for our purposes we focus on the leader's ego network (or close network) since we are interested only in mental model convergence within a team, and direct followers are likely members of a leader's close/personal network.

One characteristic that may influence outcomes within the leader's ego network is related to the density of the network itself. Density, or how the followers are connected to each other within the leader's ego network, may be particularly important in mental model convergence. In dense networks the leader personally encourages all team members to establish contacts/links to other team members, disseminates information through these links, and promotes development of perspective of each team member for every other team member (Balkundi & Harrison, 2006).

Leaders that model and facilitate followers developing and exploring relationships with all other team members (i.e., participative) in the leader's ego network may promote mental model convergence and development of a shared group problem function. Thus, participative leadership can be mapped to densely connected networks. Contrarily, LMX leadership which segregated team members into a least two subgroups can be mapped to poorly connected networks.

Centrality, which describes the position of a node relative to others in the network (Scott, 2000), can be important for leaders because central leaders tend to link team members who may not normally interact together and tend to have fairly comprehensive views of the social structure within the team (Balkundi & Harrison, 2006). In our model, we assume that a leader should always be represented as a central node of the social network because it is his/her ego network.

5. General research focus

These leadership and social network concepts, together with the notion that teams may emerge in various forms, was the basis for development of an agent-based model to explore the changing dynamic within homogeneous and heterogeneous teams as they attempt to converge towards a team mental model and team performance. Specifically, we examine whether an emergent form representing team homogeneity or team heterogeneity has any impact on team mental model convergence and/or early decision making performance. Further, within both conditions, we explore whether LMX or participative leadership may be a more appropriate approach, especially given the underlying social networks that may be typified by these leadership forms. An agent-based model enables the changing and emerging team mental model to be captured and assessed as leaders interact with team members over time.

We expect that individuals that are more similar (i.e., homogenous) may be able to converge on a team mental model more quickly, as there is less processing time involved in understanding perspectives that are like your own personal perspective. This would favor homogeneous conditions over heterogeneous conditions, where processing time to understand different perspectives from that of your own perspective is likely higher. Additionally, from a leadership view, we expect that participative leadership and its underlying densely connected network also may promote a more rapid approach to mental model convergent, as perspective sharing is encouraged and modeled by the leader. Conversely, in conditions where LMX leadership emphasizes some members at the expense of other team members, reflected by poorly connected networks, mental model convergence may be difficult to achieve.

Regarding team decision making performance, we speculate that participative leadership in heterogeneous teams may enable a team to traverse a problem space more completely than teams where perspectives are generally similar within the team. This broad and diverse perspective within heterogeneous teams, fueled by a leadership with a densely connected social network, likely enables teams to more accurately represent the problem at hand, as many more alternatives may be considered and discussed. The chance of not seeing some critical aspect of the problem is likely reduced. Whereas, in teams where most members think alike, if a critical problem aspect has not occurred to one team member, it likely has not occurred to other team members either. Thus, problem space exploration may be limited, which could be a critical deficit if the problem involves innovation.

Overall, although the model is exploratory, based on the theoretical development we can produce some general assertions to direct the research: first, we expect that homogenous teams in either leadership condition will likely converge faster, which is important if a team's primary problem solving function emphasizes speed. However, if a team's primary problem solving function emphasizes ingenuity and innovation, heterogeneous teams may better address the quality of the decision at the expense of speed. Second, we expect that consistent with the concept of “team mental model” (and ultimately group level of analysis), we expect that participative (i.e., group level) leadership with a focus on egalitarian and shared responsibility and an underlying densely connected network will better promote both team convergence and decision performance.

6. Methods

We implemented an agent-based simulation model of team development processes using Wolfram Research Mathematica (http://www.wolfram.com/mathematica/). Details of the model are described below.

6.1. Team setting

Our model represents a development process of a team working on a problem representation task in a one-dimensional continuous problem domain between 0 and 100 (arbitrarily chosen). A true problem function (TPF) is constructed by assigning random numbers between 0 and 1 to several sample points in the problem domain and then interpolating between those random sample values (example shown in Fig. 1, top). At each point in the problem domain, the value of the TPF represents the best choice for that particular aspect of the problem. The objective of a team is to collectively estimate the shape of the TPF as accurately as possible.

6.2. Agents

A team consists of N interacting agents (i.e., team members). Research on team size suggests a curvilinear relationship between team size and team effectiveness (Guzzo, 1988; Guzzo & Shea, 1992; Hackman, 1990).Very small teams (i.e., 2 or 3 people) may lack diversity of perspectives (Jackson, 1996), whereas larger teams (more than 10 members) tend to divide into subteams, which hinders effective team interaction (Likert, 1977). Therefore, we use $N=10$ (the maximum team size suggested before subteams are likely to occur) to produce the results discussed in the following section. Each agent has its own individual problem function (IPF), which is constructed by adding random noise to the TPF. The IPF represents an agent's personal view of the problem and is

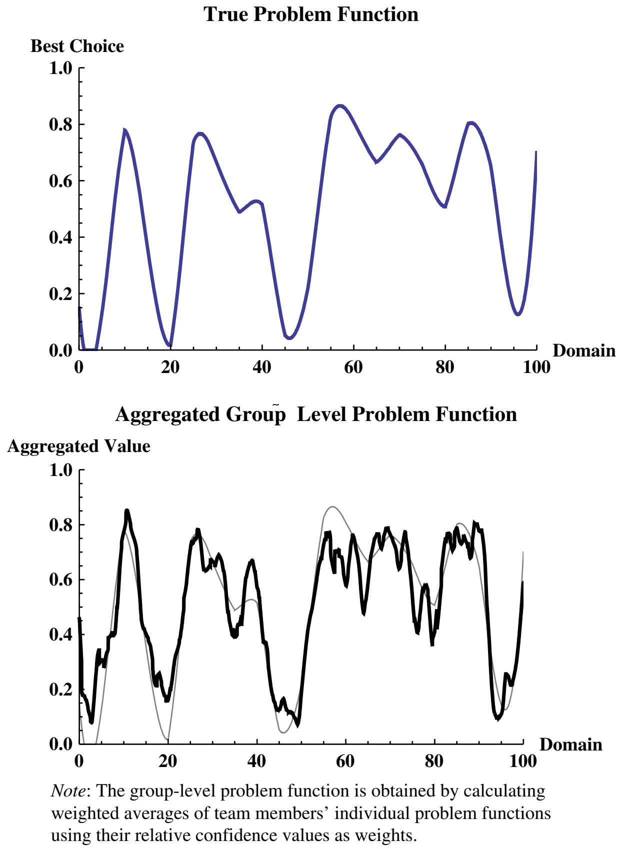


Fig. 1. An example of the true problem function and the group-level problem function.

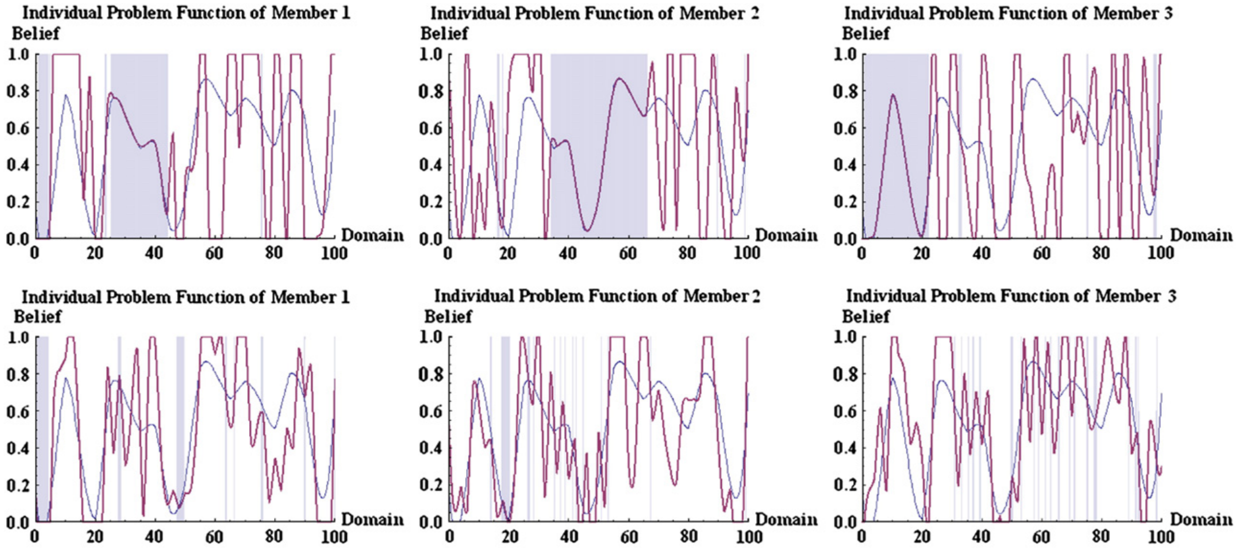
allowed to change very slowly during the information elaboration process (i.e., learning through discussion). An agent has direct access to its own IPF only. None of the agents have direct access to the TPF or another agent's IPF.

Additionally, we introduced a domain of expertise to each agent's IPF, inside which the agent's IPF is closer to the TPF, and the agent's self-confidence function (discussed later) reflects greater values than outside the domain. A domain of expertise is formulated as a randomly selected continuous finite range in the 0–100 problem domain, whose width does not exceed 50. We also introduced an experimental parameter, called "Group Heterogeneity in Domains of Expertise," H, whose values range between 0 and 1. $H=1$ means that each agent has a clear domain of expertise, i.e., it has nearly perfect knowledge about the TPF within its domain of expertise but almost no knowledge outside (example shown in Fig. 2, top). This represents the "heterogeneous" (i.e., compilation) condition. In contrast, when $H=0$, the agents have no clear domains of expertise and there is no difference in accuracy between inside and outside the domain of expertise (example shown in Fig. 2, bottom). This produces a condition in which all the IPFs within the team look similar, representing the "homogeneous" (i.e., composition) condition.

In addition to the IPF, each agent has N separate confidence functions, one of which represents self-confidence while the other $N-1$ represent confidence for other team members. Representing the knowledge about "who knows what" within the team, these confidence functions constitute the mental model of the team that each member has in mind. As confidence values represent the relative importance of each member on a specific aspect of the problem, the sum over all team members is always conserved to 1 at any time and point in the problem domain. The group-level problem function is obtained by aggregating the IPFs of all team members, using the average of confidence values given to each member for a specific location in the problem domain as a weight (see Fig. 1, bottom). Those confidence functions will change over time based on interactions between team members throughout the information elaboration process, which will be explained in more detail below.

6.3. Information elaboration process

The information elaboration process is informed by McComb's (2007) three phases of mental model convergence, i.e., orientation, differentiation and integration. Specifically, orientation is represented by a speaker sharing an opinion (see Step 2, below), differentiation represented by a listener's evaluation process compared to their IPFs (see Step 3, below) and finally, integration represented by subsequent modification of confidence functions about the speaker in each agent according to the



Note: *N*=3.

With *H*=1 (top), team members have clear domains of expertise (represented as shaded vertical lines) but their IPFs (represented as square-topped functions) are completely wrong outside those domains, where the TPF is represented by the smoother function. Each person's area of expertise reveals the two functions match/overlap each other.

With *H*=0 (bottom), the IPFs (represented as square-topped functions) are similarly off from the TPF (smooth function) regardless of location in the problem domain, as unique expertise of any of the three team members is low/limited.

Fig. 2. Domains of Expertise Represented As the Closeness of the IPFs to the TPF. Example with heterogeneity in domain of expertise (H = 1). Example with homogeneity in domain of expertise (H = 0).

feedback given by the team (see Step 4, below). More detailed information regarding how the team information elaboration process is simulated follows.

1. A speaker is selected out of *N* agents, using their overall self-confidence as the probabilities of selection. An overall self-confidence of an agent is calculated by integrating the agent's individual self-confidence function over the entire problem domain. This assumption models the notion that the more self-confident a member is, the more often he/she speaks.
2. *Orientation*. A topic (i.e., a specific location within the problem domain) is selected from the entire problem domain, using the speaker's self-confidence function as a probability distribution function. This assumption models the notion that people tend to speak about topics in which they have more confidence. Then, the speaker expresses his/her opinion on the selected topic (i.e., the value of his/her IPF at the selected location in the problem domain).
3. *Differentiation*. The expressed opinion is evaluated and responded to by team members around the speaker as well as by the speaker her/himself, based on the following two criteria:
   a. How different the expressed opinion is from the value in the evaluator's IPF (d, $0<d<1$).
   b. How confident the evaluator is on the spoken topic (c, $0<c<1$).

   The overall response of the evaluator is given by:

   $$r = (1-2d) \times c(-1<r<1) \tag{1}$$

   This formula reflects that if the difference between the expressed opinion and the evaluator's individual opinion is less than 0.5, the response is positive, or "thumbs up" (otherwise negative, or "thumbs down"), and that if the evaluator is confident on the spoken topic, his/her response is greater in its magnitude (otherwise smaller, meaning more neutral response). Note that this formula always produces positive self-reinforcement to the speaker him/herself (i.e., when $d = 0$). This assumption models the increase in self-confidence gained by speaking up in a group.
4. *Integration*. Each agent modifies his/her confidence function for the speaker based on another experimental parameter, "Level of Mutual Interest", M, whose values range between 0 and 1. $M = 0$ means that confidence values change solely based on the evaluator's own individual response, while $M = 1$ means that confidence values increase or decrease solely based on the average responses around the evaluator. After all, if the speaker's opinion is considered positively, the confidence function for the speaker is locally pushed up by adding a small triangular function (whose maximal height and width were set to 0.1 and 10 in the following experiments, respectively) at the location of the topic spoken. If the speaker's opinion is considered negatively, the confidence function for the speaker is locally pulled down by subtracting the same triangular function. Then the confidence

values for all team members are normalized to conserve their sum to 1, which causes relative decrease/increase of confidence for other members due to increase/decrease of confidence for the speaker. In addition, only when the speaker's opinion is considered positively, each evaluator modifies its own IPF slightly so that its difference from the speaker's IPF on the selected topic be reduced by a factor of λ (for example, $\lambda = 0.3$ means the difference can shrink by up to 30% in one learning event). This represents individual learning through discussion. In reality however, learning is a slow process compared to the speed of discussion (Edmondson, 1999; Lee & Klein, 2002), so we let $\lambda = 0.001$ for the simulations presented in this paper.

5. The above steps (1 to 4) are repeated for a fixed number of iterations. To produce the simulation results presented below, we used 500 iterations as one information elaboration process.

6.4. Social network structure

In our model the interaction and convergence described above takes place only through social ties between members in a network that is pre-formed by the leader (i.e., the leader's ego network). To represent different leadership styles in social network structure, a final experimental parameter "Number of In-group Members," K, is introduced, whose values range from 2 to N. A social network is created using this parameter in the following way: first, a fully connected network of K members (including the leader) is generated to represent an in-group cluster. Then the remaining N–K out-group members are connected to the leader with a single tie. With this algorithm, $K = 2$ reflects a star-shaped network more likely typified by LMX leadership, while $K = N$ represents a fully connected network more likely typified by participative leadership (see Fig. 3).

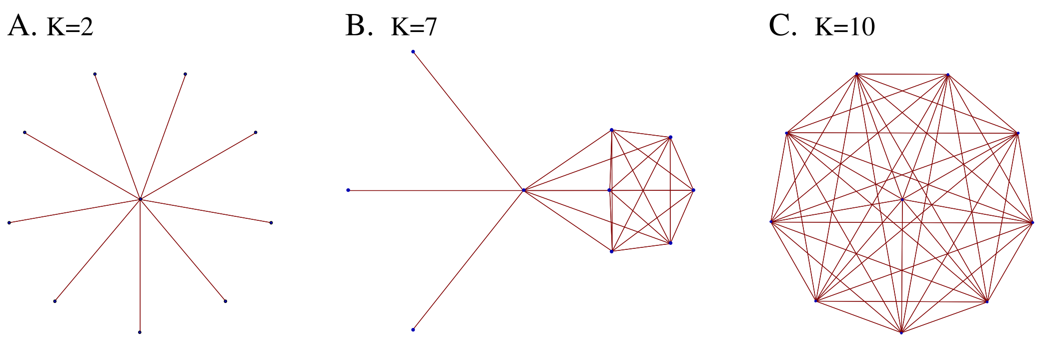
We conducted Monte Carlo computer simulations, running 20 independent simulation runs for each parameter setting and aggregated the results for analysis. The Monte Carlo technique employed in this computer simulation resembles techniques widely used in the physical sciences and mathematics (cf., Binder & Heermann, 2002; Caflisch, 1998) and refers to the use of random sampling of distributions. This technique typifies the idea of importance sampling, which is a sampling process repeated many times to allow for properties of the system to be determined by averaging certain quantities over the many states generated.

All data inputs are from synthetic data, generated from parameters guided by theory and established specifically for this simulation. The parameter settings we systematically experimented were: $H = 0$ or 1, $M = 0$ or 1, and $K = 2, 3, \ldots 10$. Thus, the total number of simulation runs conducted was $2 \times 2 \times 9 \times 20 = 720$. Although simulation runs can be any size, one can quickly reach a point where additional runs provide no additional significant information. We were more than satisfied that 20 simulation runs revealed enough similarity to indicate that no additional runs would be productive. More information on use of Monte Carlo simulations within team research can be found in Dionne and Dionne (2008) and Sayama et al. (unpublished).

6.5. Metrics for team development and performance

In each simulation run, team development and performance were characterized using two unique metrics. One metric, the convergence level of mental models, is defined as the total disagreement of confidence functions existing among team members, *times −1* (i.e., multiplied by −1). Therefore, the maximum of this metric is 0, where exactly the same confidence functions are shared by all team members. As the disagreement among mental models becomes larger, this metric becomes lower. The difference in this metric before and after the information elaboration process is considered the "Development of Mental Models."

The other metric is the quality of the group-level problem function, which is defined as the sum of the square distance between the group-level problem function and the TPF over the entire problem domain, *times −1*. Therefore, the maximum of this metric also is 0, where the group-level problem function precisely matches the TPF. As the group-level problem function becomes



Note. N=10.

A. K=2 reflects a star pattern (low density)
B. K=7 reflects an in-group with higher density and an out-group with low density
C. K=10 reflects a fully connected network (high density)

Fig. 3. Social network structures.

incorrect, this metric becomes lower. The difference in this metric before and after the information elaboration process is considered the "Improvement in Group-Level Problem Function."

Group-level problem function was selected as a performance indicator in that accurate and appropriate estimation of the complexity of a problem is a key primary element in effective decision making (Kaplan & Simon, 1990). Moreover, we are concerned with early team tasks that may logically follow formation of team mental models and have the capability and/or potential of involving all members of the team. As such, we selected a key first stage in team problem solving, that of problem representation (i.e., development of a group-level problem function).

The above two metrics were measured continuously during the simulation runs, while the differences between their initial and final values are used as experimental results.

7. Results

7.1. Leadership and social network structure related to mental model convergence

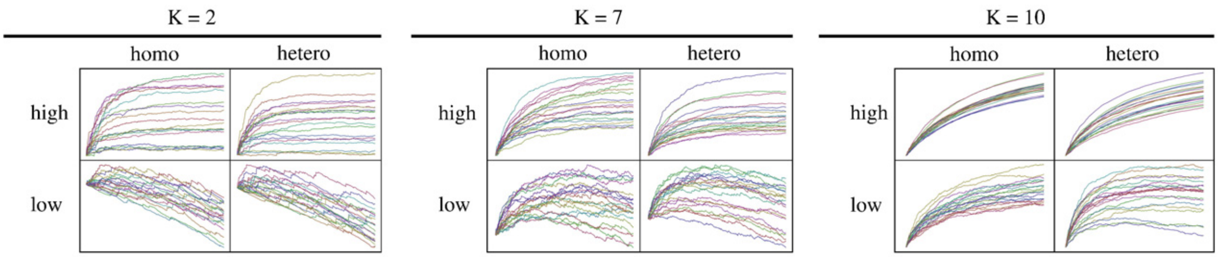
As seen in Fig. 4, high mutual interest within the team impacted the ability of teams to achieve convergence of a team mental model. Lines on the plots represent the independent results from the 20 Monte Carlo production runs. The increasing lines within the high levels of mutual interest conditions indicated convergence. When teams did not have high levels of mutual interest (i.e., experienced self-interested behavior on behalf of members), LMX leadership did not promote mental model convergence, regardless of whether the majority was the in-group ($K=7$) or out-group ($K=2$). Although initially majority in-groups moved toward convergence, as time passed these teams moved toward degradation of the team mental model. Contrarily, participative leadership ($K=10$) did promote convergence, even when teams experienced self-interested behavior.

Fig. 5 provides an average view of mental model convergence over the changing social structure in the various homogenous/heterogeneous and levels of mutual interest conditions. Clearly, emphasis on a fully connected network ($K=10$) by a leader produced stronger mental models regardless of condition. As the in-group continued towards the more participative environment, the situation became favorable for improving the mental model convergence as well, regardless of condition.

7.2. Leadership and social network structure related to improvement in group-level problem function

As seen in Fig. 6, variation in the social network structure somewhat impacted the ability of teams to improve their group-level problem function. Similar to the mental model convergence outcomes, improvement in group-level problem functions seems related to emergent team form and level of mutual interest. When in-group membership represented a minority ($K=2$), a homogeneous team where an opinion is accepted by team members resulted in a decreasing group-level problem function (i.e., not estimating the problem accurately), where as lower mutual interest in this condition did not significantly affect the group-level problem function. There was a slight increase in group-level problem function when teams were heterogeneous and had high mutual interest within this in-group condition, and no significant change when mutual interest was low.

The results are slightly different when in-group membership represented a majority ($K=7$). Similar to the minority in-group condition, in the homogenous emergent form (i.e., composition) there was a decrease in group-level problem function when there was higher mutual interest, and no change when there was lower mutual interest. However, in the heterogeneous emergent form (i.e., compilation) with higher mutual interest there was slight improvement in the group-level problem function, while with lower mutual interest there was no significant change in group-level problem function (see Fig. 6).



Note: Each of the graphs above shows 20 time series plots, which correspond to 20 independent simulation results in each parameter setting. The horizontal axis indicates time while the vertical axis indicates development of mental models (i.e., change of their convergence level relative to initial values). The labels "homo" and "hetero" correspond to homogenous groups (H=0) and heterogeneous groups (H=1), respectively, while the labels "high" and "low" correspond to high levels of mutual interest (M=1) and low levels of mutual interest (M=0), respectively. K=2 reflects the in-group is the minority (LMX); K=7 reflects the in-group is the *majority (LMX); K*=10 represents participative leadership.

Fig. 4. Development of mental models by leadership condition.

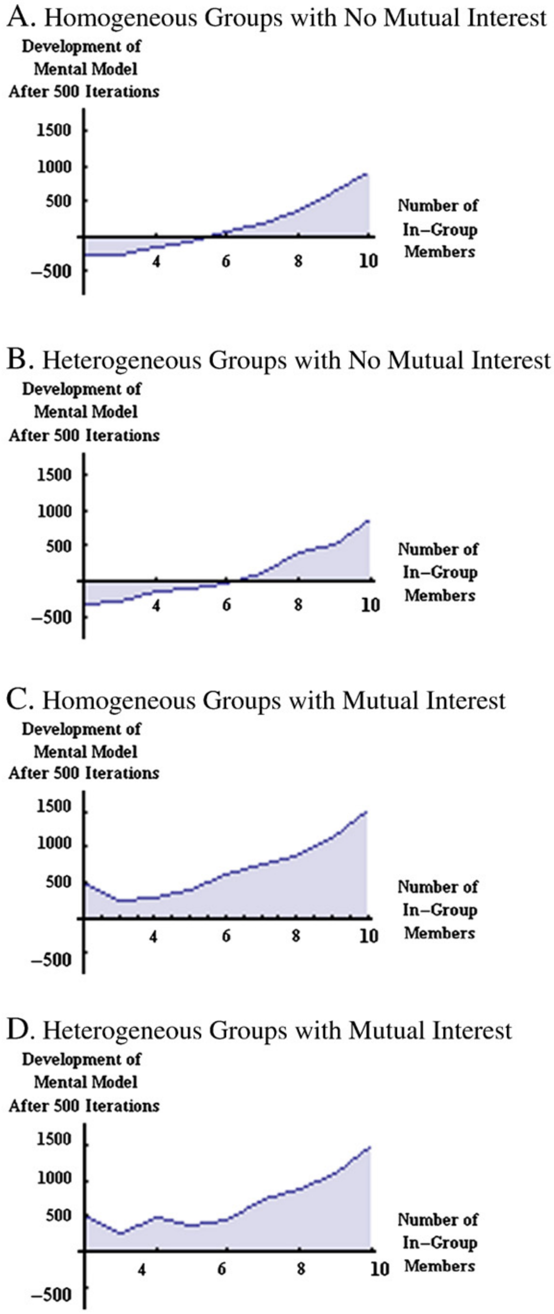
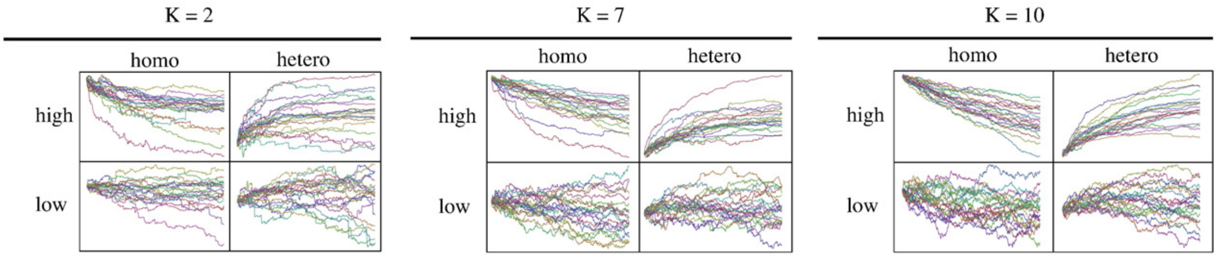


Fig. 5. Averages for development of mental models.

This result is similar but more pronounced when we view a participative leadership condition ($K = 10$). In the composition condition, with higher levels of mutual interest the group-level problem function showed a pronounced decrease, and only a moderate decrease when mutual interest was lower. In the compilation condition, there was a moderate improvement in group-level problem function when mutual interest was high, and no significant change when mutual interest was low.

Fig. 7 provides an average view of improvement in group-level problem functions over the changing social structure in the various homogenous/heterogeneous and levels of mutual interest conditions. An interesting pattern was that in three of four conditions (see A, B, C on Fig. 7) where the in-group represents the minority ($K = 2$), this structure tended to minimize the degradation of the problem function. Only in diverse groups with a high level of mutual interest were there significant improvements in group problem function as the team became more fully connected (see D, Fig. 7).



Note: Each of the graphs above shows 20 time series plots, which correspond to 20 independent simulation results in each parameter setting. The horizontal axis indicates time while the vertical axis indicates improvement in group-level problem functions (i.e., change of their qualities relative to initial values). The labels "homo" and "hetero" correspond to homogenous groups (H=0) and heterogeneous groups (H=1), respectively, while the labels "high" and "low" correspond to high levels of mutual interest (M=1) and low levels of mutual interest (M=0), respectively. K=2 reflects the in-group is the minority (LMX); K=7 reflects the in-group is the majority (LMX); K=10 represents participative leadership.

Fig. 6. Improvement in Group-Level Problem Function by Leadership Condition.

8. Discussion

Using a convergence process outlined by McComb (2007) to guide information elaboration procedures, and leadership style to inform social network structure, we developed an agent-based model and evaluated two critical aspects of team development and performance: mental model convergence and problem representation. Regarding mental model convergence, a clear picture emerged emphasizing the primary role leadership and mutual interest play in promoting a shared mental model among team members. Whenever mutual interest among the team is high, teams were able to converge mental models in all leadership conditions, regardless of their diversity level. However, only participative teams were able to converge mental models when mutual interest was low. Apparently, when subgroups have been identified by the leader (i.e., LMX) and mutual interest among team members is low, there was no ability to converge.

This lack of mental model convergence may affect future performance of the fragmented team, as there is little agreement or understanding of "who knows what" or what role members play on the team. Leaders who use this particular style run the risk of preventing optimal team performance in that the team does not have a clear perspective of how members are expected to contribute to the team or even what members can provide what expertise.

Impeding the convergence of a team mental model may be the lack of density within the social network structure of the team, combined with the central role a leader played in information elaboration. Social network structures more likely resembled a star formation where communication generally routed through the leader very frequently, but was limited between the in-group and the out-group. Thus, the leader played a strong central role in the structure, but did not promote density within the network in that some groups were favored over others, and this was likely reflected in the weakened information elaboration process.

Conversely, participative leaders seemed to promote mental model convergence, regardless of the diversity or levels of mutual interest within the team. The encouragement of connections among all team members was likely a primary component in ensuring teams converged regarding their understanding of "who does what" and "who knows what" within the team. Leaders who valued all members of an ego network likely set the stage for team members to do the same, and hence a clear focus developed and became integrated throughout the team. The fully connected network likely facilitated this strong understanding of team roles and responsibilities.

Thus, the emphasis on developing a dense leader ego network may be the driving force in team mental model convergence. A leader encouraging all members to participate is likely to produce a fully connected network where leader centrality is downplayed over time. The strength of dense social network structure may be its ability to promote a balanced information elaboration process.

Practically speaking, it would seem prudent for leaders to use a more participative style, especially when teams are newly forming or experiencing significant change and require development of a comprehensive team mental model. Having "favorite" team members or identifying a core "inner circle" of members apparently cannot promote the critical and primary step of developing a unified and organized team knowledge structure unless the team is fairly diverse and mutually interested in having the team succeed.

Regarding team problem representation, an interesting pattern emerged. Regardless of the leadership style, when teams were homogenous in nature and had high mutual interest, a decrease in team problem function occurred. An underlying issue related to this finding may be the phenomena of groupthink (Janis, 1982), where teams may be derailed in their ability to solve problems due to the similarity of their beliefs, values and interests. There may be little exploration among team members regarding diverse and/or opposing viewpoints, and as such, accurate representations of a complex problem may be quite difficult.

Practically speaking, leaders (and organizations) may want to avoid building teams where members are fairly similar in expertise and viewpoints. Although diversity does not guarantee improved problem representation, more diverse teams did not experience declines in their ability as did the homogenous teams. Moreover, diverse teams where mutual interest levels were high were able to produce improvements in problem representation. As such, combining diversity with training related to information elaboration processes that allow feedback and perspective development may result in higher team performance related to the initial phases of team decision making (i.e., problem representation).

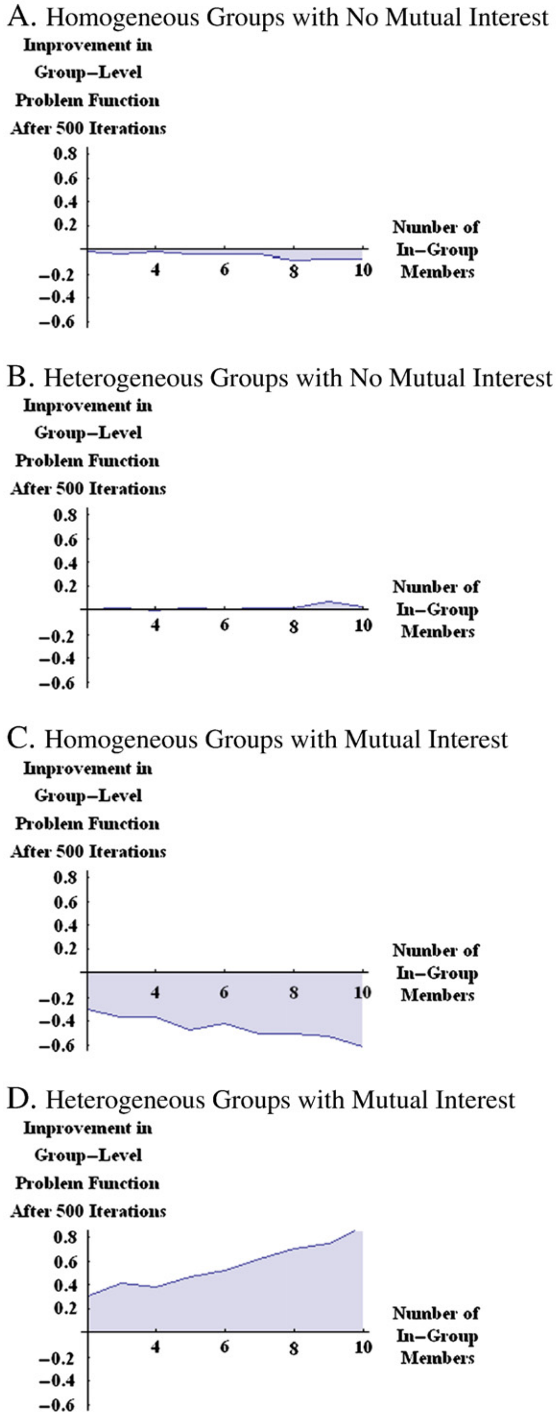


Fig. 7. Averages for improvement in group-level problem function.

However, related to conditions when problem function degradation occurred (i.e., homogeneous teams with high mutual interest), an interesting revelation was that LMX leadership tended to minimize the degradation. In other words, LMX leadership could be a useful strategy in situations where leaders have no opportunity to diversify teams, but could certainly try to avoid further movement towards incorrect assumptions and problem representations. In these situations a leader may want to split these homogenous members into subgroups to minimize the potential for groupthink by limiting the opportunity for an identical information elaboration process.

Thus, both leadership styles may be useful in managing teams, especially teams that are poised for success through diversity and mutual interest. Unfortunately however, not all leadership scenarios and situations have the luxury to focus on optimization, but rather may focus on minimizing damage. In situations such as these (i.e., homogeneous teams with high mutual interest) the leader can attempt to “stir the pot,” so to speak, by creating subgroups to artificially provide boundaries between teams that likely would not have considered a variety of alternative perspectives.

Although preliminary in nature, these findings tend to indicate that a better understanding of the underlying social network may have value in understanding how leaders promote mental model development and encourage appropriate problem representation. In our model, an increase in the membership of the in-group reflected the development of direct relationships between team members that were not facilitated by a leader. Therefore, although the leader–follower dyadic relationship has been the core component of LMX leadership, the social networking component of our research modeled the potential benefit and power of team members establishing unique relationships between each other.

Current LMX research (Boies & Howell, 2006; Graen & Uhl-Bien, 1995; Sherony & Green, 2002) promotes developing high quality relations with each follower, and suggests this leads to better dynamics among the team. Our research may shed light on that notion, in that better dynamics among the team may need to come in the form of dyadic relations between each and every team member (i.e., a fully connected network). Leaders may want to encourage all members to form their *own* beneficial social ties with each and every member of the team—ones that *do not need* leader facilitation or an understanding of where each person stands on quality of relations with their leader. It may not be enough for the leader to establish good relations with each follower (i.e., leader–follower dyad) if each follower does not establish good relations with every other follower (i.e., follower-follower dyad).

The fully connected network (in diverse teams with mutual interest) was key for problem representation, and the fully connected network also was key for mental model convergence, no matter the condition. This suggests that LMX (and participative leaders) focus more specifically on the underlying social network that develops within the team. Leader–follower dyad development may share importance with follower-follower dyad development, and thus social networks may need stronger consideration within leadership theories, although more research is needed to better understand this concept.

8.1. Limitations and future directions

Simulations provide a means for examining level-specific theoretical relationships between dynamic and complex constructs (Kerr & Tindale, 2004). Although powerful in their ability, “model” is the key word to emphasize. Models represent interactions, but on a lower level of sophistication than actual team-based interactions. Although we enabled team member confidence levels in other team members to change according to information elaboration processes and began the process of learning, we did not simulate longer time steps (i.e., years) that would have better enabled team members to learn. Future research could model longer periods of time to include more substantial learning and increase the level of sophistication within the model, further enhancing our understanding of how teams may shift mental models and solve problems.

Additionally, because this research represents a preliminary step in identifying leadership's relevance in team mental model convergence, we selected only two specific leader styles that were relevant at the team level of analysis. However, future research could examine other leadership models (i.e., transformational/charismatic, transactional, individualized leadership) and assess the impact they may have on mental model convergence and problem representation. It may be that other leadership styles are better suited for team development and performance and as such, this line of investigation should continue.

Another limitation of this research is the notion that interpretations are limited to the assumptions and preset parameters in this simulation. Different assumptions–for example, considering a different team size, simulating different social network structures where leaders do not necessarily occupy the central position, or examining other leadership styles (i.e., transformational/charismatic, transactional, individualized leadership)–may produce significantly different results. Although our assumptions are based on existing literature, this research represents only a preliminary step in identifying leadership's relevance in team mental model convergence.

Although limited in generalizability, our model does provide a starting point for investigation into how leaders may influence mental model convergence and early stages of team decision making. There is evidence that leadership styles matter when it comes to mental model convergence and the ability of a team to accurately represent a problem. Future research should seek to expand the generalizability of our findings by conducting field experiments and organizational research that both test and expand these notions related to leadership and team mental model convergence. This line of investigation is ripe for inclusion of organizational factors such as climate or culture, and additional examination of social network structure influences.

Acknowledgments

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