Mental Models, Team Mental Models, and Performance: Process, Development, and Future Directions

Janice Langan-Fox, Jeromy Anglim, John R. Wilson¹

Abstract. Since the 1940s, researchers have grappled with the notion of a *mental model*. The concept is eminently reasonable and somewhat seductive, but presents us with a number of difficulties regarding its incompleteness, multiplicity, and inconsistency. Not the least of these difficulties is the problem of “capturing” (measuring) mental models, and still more difficult, capturing a *team mental model*, an extension of the earlier term. Once captured, finding an appropriate analytic procedure to analyze team mental models has challenged researchers for a long time. Nonetheless, the literature suggests that the construct is well worth the trouble, with many applied benefits especially to industry. In the present work we set out to (a) review the notion of team mental models (TMM); (b) identify the key concepts and thinking behind their development; (c) demonstrate how they support teamworking performance; and (d) outline a three-phase model of TMM development. Details on TMM measurement are given, before concluding with a discussion of the difficulties facing researchers who wish to study and utilize the notion, and some of the pressing research issues that need investigation.

1 INTRODUCTION

1.1 Mental Models

For nearly 60 years the notion that people form mental models of their environment has been a topic of psychological enquiry. Ergonomics researchers of human-machine systems have also long-regarded the concept as being self-evident. However, developments of the mental model

¹ Citation Information:

Langan-Fox, J., Anglim, J., & Wilson, J. R. (2004). Mental models, team mental models, and performance: Process, development, and future directions. *Human Factors and Ergonomics in Manufacturing & Service Industries*, 14(4), 331-352.

Copy of record is available at: <https://doi.org/10.1002/hfm.20004>

Janice Langan-Fox, Jeromy Anglim, Department of Psychology, The University of Melbourne, Victoria, Australia; John R. Wilson Institute for Occupational Ergonomics, University of Nottingham, United Kingdom; Correspondence to: Janice Langan-Fox, Department of Psychology, University of Melbourne, Parkville, 3052, Victoria, Australia. E-mail: j.langan-fox@psych.unimelb.edu.au

notion within ergonomics and cognitive psychology (e.g., Gore, 2002) appear to have followed independent paths (Wilson & Rutherford, 1989). Thus, it is not surprising that there is no agreement about definitions of mental models. But taken together, accounts indicate that mental models (MM) are internal (mental) representations of objects, actions, situations or people, and are built on experience and observation, of both the world in general and the particular entity of interest (Wilson, 2000).

Here we (a) review the notion of team mental models (TMM), (b) identify the key concepts and thinking behind their development, (c) demonstrate how they support teamworking performance, and (d) outline the phases of TMM development. Specifically, the relevant literature is examined and major themes extracted. After examining the significance of the TMM concept and some of the related premises and hypotheses, we explain the three phases in the development of TMMs and then gives details on the measurement of TMMs, before concluding with a discussion of the difficulties and doubts facing researchers who wish to study and utilize the concept.

One of the interesting aspects of this paper is that it is authored by researchers with varied experiences—some whose first exposure to the notion of mental models was in the understanding and identification of individual mental models, those whose first and primary exposure has been to look at team mental models, as well as those who have come at it from the notion of team working. Therefore, it is fascinating for this mixed group to begin to examine whether the notion of team mental models, as it is understood by most of the communities studying them, will be challenged by the same definitional, conceptual, and methodological problems as those which have dogged the notion of individual mental models.

1.2 Applied Considerations

From a human factors perspective, MMs are simulations that are run to produce qualitative and quantitative inferences, underpin our understanding of a system, and allow us to describe, predict, and explain behavior of a system. They can contain topography, structure, function, and operation of the system as well as spatial, causal, and contingency relations. They are instantiated each time they are required and therefore vary over time both in terms of memory degradation and refinement through learning. If we can find a way to identify and represent the mental models held by people in a particular situation, and can communicate these models successfully to designers, planners and managers, then products and jobs can be designed to better match the needs and expectations of people. Researchers in human computer interaction have picked up the notion, attempting to define user models. In Norman's (1983) view, by understanding the

potential users' mental model and by adapting their own conceptual model accordingly, designers might develop a system "image" that better matches, sustains, and develops an appropriate user mental model.

In most circumstances people will construct and employ several mental models—of the behavior of the physical variables in the systems (electrical, chemical, or mechanical), or of the structure and form of the system, or even of the rules governing the operation of the system for instance. As well as being dependent on the task, the exact number of mental models generated in a particular situation is dependent on the theorist's decision on how to classify mental models and what level of difference qualifies as a unique mental model. These mental models may vary in their degree of abstraction and may be formed from observation of the system itself, from knowledge of operating, emergency, or maintenance procedures, from instructions and training, or even from experience of other similar systems worked on in the past. However, the eminently reasonable even seductive notion of a mental model does present us with a number of potential limitations or difficulties, especially measurement difficulties, to do with how to represent a phenomena that is often characterised as having an incomplete, multiple, and inconsistent structure. The challenge for practitioners aiming to utilize the concept and others who wish to extend the concept to the team level is to operationalize the concept in a manner that is both readily measurable and theoretically clear.

2 TEAM MENTAL MODELS

It can be seen from the foregoing that MMs have potential applications in industry. In addition, team mental models, an extension of the mental model concept, are also of benefit. The term *team mental model* embraces two notions of great theoretical and practical interest and also some controversy in human factors and occupational psychology: mental models and teamworking. Teamworking means groups having common valued goals, multiple tasks and complementary skills, internal interdependence and coordination, being mutually accountable for methods, resource use and outcomes, and taking on extended (managerial) responsibility. Originally, their growth was on the basis of sociotechnical systems theory (Langan-Fox, 2003; Langan-Fox, Code, Gray, & Langfield-Smith, 2002) and quality of work life movements, followed by stagnation in the 1980s. They have had a renaissance in application and research in the past 15 years, within safety-critical industries, manufacturing, the military, and the service sector (Genaidy, Karwowski, Succop, Kwon, & Alhemoud, 2000; Zolnierczyk-Zreda, 2000). Just like mental models, there are

a number of fundamental questions facing researchers and practitioners of teams. How do we set up teams from a technical and function-allocation point of view; what is a good mix of skills; how many people are needed or are ideal in a team; what do we do about excellent staff who do not want or cannot thrive in teams; how do we handle conflict between and within teams; and how can the total organization handle these “mini-enterprises” within them (Wilson & Whittington, 2001).

Nonetheless, it is a fact that teams now form a critical component of organizational productivity with many of the tasks that teams are required to complete surpassing the cognitive capabilities of a single individual (Cooke, Salas, Cannon-Bowers, & Stout, 2000). These developments have brought a new urgency to obtaining a deeper understanding of teamwork, shared cognitions, and team dynamics (Gibson, 2001; Mohrman, Cohen, & Mohrman, 1995; Nonaka, 1994; Schendel, 1996; Spender & Grant, 1996).

From the groups and teams literature, we know that to work together successfully, teams should perceive, encode, store, and retrieve information in similar ways. When team members share similar and accurate mental models (we return to issues of similarity and accuracy later in this paper), members perform more effectively (Cannon-Bowers, Salas, & Converse, 1993) and develop common knowledge—a Team Mental Model (Katzenbach & Smith, 1993). Levesque, Wilson, and Wholey (2001) describe shared mental models as knowledge structures held by members of a team that enable them to form accurate explanations and expectations of the task; to coordinate their actions; and adapt their behavior to demands of the task and other team members (see also Cannon-Bowers et al., 1993; Mohammed & Dumville, 2001). Explorations of shared knowledge focus on the extent of overlap in the mental models of individual team members, that is, the presence and strength of a TMM. The notion of a *shared mental model* is distinct from a *team mental model* in that the latter refers to what is shared among the members of a team as a collectivity, not shared cognition amongst dyads of individuals, which the former phrase allows for (Klimoski & Mohammed, 1994). The term *team mental model* is not meant to only refer to multiple levels or sets of shared knowledge or just to an aggregate of the individual mental models but also to a synergistic functional aggregation of the teams mental functioning representing similarity, overlap, and complementarity.

2.1 Potential Applications of the Team Mental Model Construct

Given the complex nature of teamwork in organizations, the cognitive structure (the mental model) that

team members use to organize information about team functioning is extremely important. Team mental models are thought to provide team members with a set of organized expectations for team performance from which timely and accurate predictions about team member behavior can be drawn (Converse, Cannon-Bowers, & Salas, 1991). Such knowledge forms the basis of team functioning by providing an understanding of global teamwork concepts (i.e., the team goal) and specific aspects of team performance (i.e., knowledge of special skills of team members), and implies that team members must hold knowledge structures that are compatible with those held by fellow team members. An interesting extension to the value of understanding TMMs may be in the study and implementation of joint cognitive systems (Hollnagel, 1997, 2003). Here people and computers are actors, separated in space and time, in a system of distributed thinking and decision-making. Designing work for distributed or virtual teams and using our understanding of social and cognitive processes would benefit from better understanding, representation, and application of TMMs.

Research suggests that team mental models have high utility and have the potential to:

- Make communication and coordination more efficient by requiring less communication between individuals for the same result (i.e., by using a common language) (Langan-Fox, Code, & Langfield-Smith, 2000; Langan-Fox, 2001).
- Make mutual team member learning more rapid and improve allocation of tasks and decision control through awareness of team member strengths and weaknesses.
- Provide greater collective efficacy and sharing in mental models.
- Elucidate the processes involved in achieving high performance in teams and improving coordination, communication, and superior team performance (Rouse, Cannon-Bowers, & Salas, 1992).
- Assist in the efficient use of time and planning for action by enabling team members to better predict what will be required and how they should interact with the team (Klimoski & Mohammed, 1994; Langan-Fox, 2003; Mohrman, 1993).

Evidence for a positive relationship between team mental models and performance has been reported by several authors. For instance, Walsh, Henderson and Deighton (1988) suggest that team mental models play an important role in aspects of team decisionmaking and shared information processes. Carley (1997) found that members of successful teams tend to have more elaborate and more widely shared maps than members of unsuccessful teams, but proposed that while teams seemed to have similar models, successful teams are better at elucidating their models in a wider variety of ways

than less successful teams. Despite these positive indications, there needs to be some qualification made about the TMM–Performance relationship: Houghton, Simon, Aquino, and Goldberg (2000) suggest that TMMs while improving information processing efficiency, may lead to biases similar to “groupthink” whereby the same errors occur in the team as with individual decision-makers (Staw, 1991) although groupthink tends to be used to define decision-making biases that are different to, or extensions of, those for individuals.

2.2 Premises and Unproven Hypotheses Regarding TMM and Performance

Research on TMMs can help to address some of the doubts and gaps in knowledge about MMs and teamworking, but investigations have been made difficult by many of the same issues mentioned earlier. From what we can gather however, there are several common premises that help explain why TMMs influence performance. A basic premise is that the group is an entity with psychological significance above and beyond individuals. Two other premises relate to performance hypotheses: a TMM improves team performance and team members develop a more accurate and shared mental representation over time through increased interaction. There are areas of contention (unproven hypotheses) that require investigation and involve conceptual clarification of the issues such as the nature distributed knowledge, the type and number of TMMs, and measurement. Specifically,

- Should the TMM concept only incorporate the idea of common understanding or should it also includes the notion of “sharing the load” as in distributing expertise across the team? This is a critical concern in decisions on the number of staff required in control rooms, e.g., in transport (see Wilson et al., 2001)?
- How many team members need to share an idea in a similar way across the team for it to be characterized as part of the team mental model—a critical issue concerned with communication?
- How should a TMM be measured?
- Is there only one team mental model or multiple mental models that govern different tasks, activities, and domains? For instance, it is often argued that individuals hold a number of mental models (as discussed above), that team members hold multiple mental models to actively conceptualise and process information about their group, other team members, equipment, environment, and task (see e.g., Cannon-Bowers et al., 1993; Klimoski & Mohammed, 1994; Levine & Moreland, 1991; Rouse & Morris, 1986); and that a typology of TMMs might be useful (Cannon-Bowers & Salas, 2001). As an example, Kraiger and Wenzel (1997) divided the measurement of

shared mental models into processing information, structured knowledge, common attitudes, and shared expectations. At present, there are differences in how people define TMMs and even more significant differences in how they are operationalized and measured.

2.3 Measurement of TMMs

The thorny issue of TMM measurement relates to problems of conceptualization, identification, measurement, and representation of individual mental models (see e.g., Rutherford & Wilson, 1991). Measurement is further complicated by the difficulty in analyzing mental model similarity and overlap at the team level (Klimoski & Mohammed, 1994). While a number of techniques have been developed to measure mental model similarity dyadically, the development of techniques to elicit and represent team mental models has been slow (Converse et al., 1991). The few techniques that have been generated are lacking in that they either cannot compare more than two mental models at once, or where more than two mental models can be compared, make assumptions about uniformity or normality which might otherwise be considered inappropriate. The measurement of mental model similarity must be related to some sensible mathematical construct of similarity. It should be possible to use the measure in some kind of distribution-free statistical analysis that does not rely on random sampling, since, particularly in organizations, it may be difficult to gain access to participants that would then lead to small, nonrandom samples (see e.g., Langan-Fox, Wirth, Code, Langfield-Smith & Wirth, 2001).

2.4 The Role of Ratings in the Measurement of Shared Mental Models

It is not surprising that researchers' attempts to study mental models have been constrained by the difficulty of participants to verbalize the contents of their rather volatile mental models (Knaeuper & Rouse, 1985, Morris & Rouse, 1985; Van Heusden, 1980). A wide variety of MM and TMM elicitation techniques have been explored. Most rely on the initial generation of the main MM concepts, either by the participant or by the researcher, which can prove a good deal more challenging than one might have anticipated. When the participant is responsible for the concept generation, it is more likely that a complete set of concepts specific to their own mental model will be produced than when a set of concepts is generated for general use by the researcher, even when a sample of the relevant population is involved in this process, as each set will be individualized. However, the individualization costs heavily in both time and complexity of analysis; though perhaps this is justified, if a successful and complete MM elicitation is achieved. In addition, the intangible nature and instability of mental models will mean

that concept generation is very susceptible to influence from the researcher; although prompting can help to trigger other areas of the participants' MMs, it may also jeopardize the authenticity of the participant concept list produced.

Are there other ways of helping participants to verbalize the contents of their mental models to produce a complete set of mental model concepts? Current investigations of the work of railway network signallers and controllers (Wilson et al., 2001) include studies of the related issues of workload, situation awareness, and mental models. In the latter, individual, shared, and team mental models have been examined, in principle (i.e., what is reasonable to expect in terms of MMs of elements and situations on the rail network) and practically in the field. Within this work, a number of methods have been employed to identify shared mental models (Bristol, 2004). These include relatedness ratings, measurement of participant expectations and observation of individual, shared, and team performance. Relatedness rating was selected over ordered tree, causal mapping and concept mapping techniques, for instance, because it does not attempt to elicit a full MM representation, neither structure nor content, generating concepts that reflect diversity in the MM rather than all the concepts possessed by the MM. The three different methods have been used in the normal place of work for the participants, to triangulate evidence for any shared mental models. In this work, difficulties include the challenges of getting people familiar with tasks or settings to verbalize their internal representations; understanding degrees of similarity or difference between incomplete MMs of two or more participants (and different again to representations from the investigators); knowing when a complete set of concepts has been generated; loss of informal evidence for MMs while more formal techniques are being applied; motivation of the participants and the time taken to gather data; and the complexity of the analysis procedures.

One critical decision faced by those designing for teams in various control rooms like the above was alluded to earlier in this paper, namely the degree of overlap of competencies, skills, and knowledge among the control center teams. The three classic cases for this are exemplified in Table 1.

TABLE 1. Typology of Control Centre Teams

Type of team	Description	Examples
“Kung Fu army”	Teams with well known, understood and recognized interchangeable skills; team skills may vary from relatively routine through to high level	Manufacturing production teams
“Total (Dutch) football”	Team members with their own roles and “positions” but can inter-change at times	Air Traffic Control
“Guns of Navarone”	Team contains one person of each specialism and these are rarely inter-changeable	Project design teams

Source: Edwards and Wilson, 2004, p. 26.

The typology in Table 1 can also be crossed with the distinctions between permanent / transient teams and close/distant teams. The TMMs that are likely to develop and to underpin the team’s performance in each type of team will emerge and grow in different ways and will be different in their degree of similarity and overlap across team members.

2.5 Elicitation and Representation

A confusing array of methods exist for measuring mental models (Langan-Fox et al., 2000). Figure 1 sets out the steps required to successfully capture a team mental model in an organization. Langan-Fox et al. (2000) also discussed different analysis and representation possibilities. To show how this methodology of elicitation and representation is implemented, Langan-Fox et al. (2000) performed a study in a government business enterprise in the communications industry. Both Pathfinder and Multi-Dimensional Scaling representation techniques were used as analytic tools, with an example shown in Figure 2. This example consists of three team members: TM1, TM2, and TM3.

While a number of techniques have been developed to measure mental model similarity dyadically (e.g., shared mental models between two individuals), appropriate measures of team mental models have eluded researchers. To overcome this challenge Langan-Fox et al. (2001) presented a new team mental model measurement tool based on randomization tests. Two types of task teams were examined—assigned, structured task teams and voluntary, unstructured task teams. The main deficiency of randomization tests is still their computational *blow out*, that is given computer capacity, it could take days or years to perform the full computation exactly given current computer processing speeds. An interim solution is to sample some large number of labelings, say 100,000, at random and generate a sample of the test statistic distribution. Although it may vary slightly from simulation to simulation, the *p*-value generated will be very accurate. The researcher should select a suitable difference measure that matches their understanding of the problem. As we pointed out earlier, the randomization test

(described in detail in Langan-Fox et al., 2001) will work regardless of which distance measure is used.

Figure 1 Phases in method design and development in mental model research. Source: Langan-Fox, Code, and Langfield-Smith, 2000. Reprinted with permission from *Human Factors*, 42(2). Copyright 2000 by the Human Factors and Ergonomics Society. All rights reserved

Figure 2 Pathfinder network (PFNET) for team member.

Source: Langan-Fox, Code, and Langfield-Smith, 2000. Reprinted with permission from *Human Factors*, 42(2). Copyright 2000 by the Human Factors and Ergonomics Society. All rights reserved.

3 FRAMING TMMS

3.1 Representations of TMMS

Shared mental models theory generally posits the individual as the unit of analysis (Banks & Millward, 2000). The TMM framework however represents the shared understanding of the team as something distributed among the team. TMMS are thus phenomena transcending the individual. Instead of individual mental models the concern is with the commonality of individual mental models and how these emerge within a team. The distinction between the individual and team level of analysis is what distinguishes team members' mental model from the TMM. The TMM aggregates the team-relevant individual members' mental models to extract an understanding of what is occurring at the collective level, that is, a total "landscape" perspective, which is one of the benefits of the TMM construct and elaborated elsewhere in more detail in Langan-Fox (2003).

3.2 Team Development

Too often, research tends to focus on outcomes rather than processes (Langan-Fox, Armstrong, Anglim, & Balvin, 2002; Langan-Fox, Code, Gray, & Langfield-Smith, 2002). Likewise, it is important to understand the process through which TMMS develop and are modified. For instance, Heffner (1998) found that the degree of sharedness of team members' task and team mental models positively influenced team processes and performance; and that team members' understanding of team processes contributed more to team effectiveness than did their understanding of the task—thus reinforcing the need to emphasize process.

Processes can be examined through an analysis of developmental stages that parallels the development of a team more broadly conceptualized: that improved performance is a consequence and reflection of this more developed team. Neck, Connerley, and Manz (1997) suggested that self-managing teams evolve from an initial phase to a mature, highly effective phase. They proposed a five-stage continuum of self-managing team development based on a widely accepted clinical model, the Beavers Systems Model. Tuckman's four-stage model of team development is often considered the starting point for theories of team development (Tuckman, 1965; Tuckman & Jensen, 1977). However while there is work which suggests that the progression from one stage to another is continuous and linear, in many cases teams can waiver back and forth between stages before actually progressing on to the next stage.

3.3 Team Mental Model Development and Skill Acquisition

Team behavior in organizations is affected by a combination of individual and team characteristics, tasks and roles, as well as the conditions of the overall organizational system. The literature suggests that although there are a number of taxonomies, progress towards a theory has not been forthcoming (Klein, 1997, 2000). To this end, there is gain to be made in paralleling the acquisition and development of a TMM with skill acquisition. Research into skill acquisition illustrates the way in which knowledge is acquired, structured, and represented by a novice (Langan-Fox, 2003; Langan-Fox, Waycott, & Albert, 2000; Langan-Fox, Waycott, & Galna, 1997). The new integration which draws upon the teamwork, mental model, and skill acquisition literature (see Langan-Fox, 2003, for a more complete description) is called the *Acquisition and Development of Team Mental Model* (ADTMM).

Our model describes the shared understanding of the team about the team, task, and the team context. Development is a process which consists of three learning phases identified by Anderson's ACT* cognitive skill acquisition model, that is, the declarative, knowledge compilation, and procedural phases (Anderson, 1982, 1993). In organizations, the phases of skill acquisition can be described in terms of team member challenges and experiences and how learners may be affected while completing the team task. Figure 3 illustrates the development of individual and/or team mental model acquisition and the various phases involved in becoming an expert, from an initial phase of acquiring facts about the task, to a final phase when they have successfully completed the task. As novices learn about teamwork, they progress through these phases and continue to engage in a learning phase that is typical of the feedback cycles found in cybernetic models.

Empirical research has been carried out but with an assortment of different conceptualizations, samples, and measurement tools making it difficult to compare studies. Thus, there is a need for an integrative framework that would aid researchers and practitioners in their interpretation of the team mental model literature, to develop hypotheses, and provide a guide for research and practical applications. Figure 4 is a development in this direction and shows particular variables that would be measured at different skill acquisition phases as shown in Figure 3, of TMM development. Thus, Figure 3 depicts a more theoretical framework while Figure 4 shows the operationalization of the theory. Details of the framework are given below.

Figure 3 Integrative skill acquisition–team mental model development framework. Source: Adapted from Langan-Fox, 2003.

Phase 1: Team Formation and Initial Developments. The first phase is the building of preconceptions based on prior knowledge. Novices initially rely on the superficial features of a domain. Thus, first impressions would help to determine initial teamwork and could be formed on the basis of team composition (individual difference): declarative knowledge (facts) such as characteristics of individuals such as age, sex, education, organizational experience, ability, and so on. At this phase, the novice could be said to have a novice team mental model (nTMM). Ackerman (1988) suggests that individual differences in ability will be of greater significance in more difficult tasks. Because teams are task-driven, an understanding of the difficulty of tasks and how to conceptualize them would be useful, and can be achieved through Hierarchical Task Analysis (for descriptions of HTA, see Annett & Duncan, 1967; Patrick, 1992; Sheperd, 1985). Mental models can be seen to contain sub-mental models (or multiple models) requiring the completion of component tasks.

Klimoski & Mohammed (1994) suggest that several steps take place in the team formation phase, which lead to shared understandings. Phase one requires the development of

a system of social and task organization and the subsequent development of a shared understanding by each member of how the team operates and of their particular role. Norms are established and roles, work processes, social norms, and commitment are negotiated and any conflicts resolved. It is likely that this is an ongoing process of refinement and adjustment, whereby members learn to adapt through an iterative feedback process.

Environmental factors. Environmental factors generally relate to the organization that the team inhabits but can be broader than this. The context is a set of factors that the novice has to contend and interact with. In the process of TMM development they can be considered similar to other facts that the novice needs to learn about: team composition variables such as sex, age, and so on. Contextual factors have yet to be illuminated through organizational research, of which there is a dearth in the TMM literature, but from the teams literature, could also include team incentives, physical proximity of team members, communication support mechanisms, and organizational culture.

Figure 4 Proposed theoretical network of causes and effects in relation to team mental models.

Source: Adapted from Langan-Fox, 2003.

Phase 2: Constructing Skill-Specific Productions Through Team Processes and Interaction. At the experiential and second phase of TMM acquisition, then team member overcomes any prior knowledge bias, and an understanding of causal relationships emerges. For instance, Rouse and Morris (1986) view mental models as embracing concepts of form, function, state and cause. In the model being outlined, it is difficult to state when

the second phase would occur. Indeed in the skill acquisition literature there is no way of accurately determining when learning passes from one phase to another (see Ackerman, 1988; Langan-Fox et al., 2002). But one example might be through the actions of individual members, say a leader, who makes various initiatives, which are then taken up by the team. Once an individual has acquired basic knowledge, they learn the combinations of requirements for shared understandings of goal accomplishment. The novice is then able to increase expertise: individuals and the team, combine simple plans into more compound plans to accomplish major goals and develop rules for selecting the best plan to achieve a given goal in a particular situation. There is also a re-organization of the knowledge that results in the development of new links between the components of the representation.

In phase two, as the novice gains some experience and involvement in the team, procedures specific to the task develop that do not require the active maintenance of declarative knowledge. Going through a trial-and-error process of discovering inadequacies in their existing knowledge and possible shortcuts that they could use, mental models develop to incorporate production rules that are constructed and compiled. The learner gradually constructs (compiles) a set of skill-specific productions that directly incorporate the relevant declarative knowledge. As Blessing and Anderson (1996) have shown, learners may be able to skip steps thus performing the team task in less time. Kay and Black (1990) also suggested that during their “plan development” phase (which can be likened to the knowledge compilation phase of the ACT* model), individuals begin to realize certain mistakes they’ve made. That is, team members learn that there are combinations of rules (norms, values of the team and others), which are often used together to accomplish goals so they are able to form plans by combining the actions that were previously represented separately. Similarly, Roschelle (1996) found that with practice, students transformed their mental models bringing them closer to an expert’s model. The role of self-correction becomes more refined and involves reviewing events, correcting errors, discussing strategies, and planning. The process is similar to describing differences between the trained and untrained, or as argued above, the acquisition of skills in the development of a team mental model. This acquisition can be fast-tracked through to phase three of the model (expert TMM) through allowing teams to engage in training courses.

3.4 Fast-Tracking the Development of TMMs: Training

How can team mental models be facilitated so that they can be acquired more efficiently and be of a higher quality? In skill acquisition, practice is important in

transitioning phases. Thus, training could deliver accurate and efficient TMMs. For this purpose, it would be useful to establish whether the TMM is “accurate and efficient” and if the team is improving its mental models. Smith-Jentsch, Campbell, Milanovich, & Reynolds (2001) found that more trained navy personnel held mental models of teamwork that were more similar to an empirically derived model of expert team performance. Ford and Sterman (1998) described an elicitation method with experts that helped to improve team mental model development. Other work (Edmondson, 1997) shows that learning, TMM development and improved performance, can occur through team interaction training. Marks (1998) highlighted two methods of training called *leader briefings* and *team interaction training*, which assisted the development of TMMs. Strategies for TMM development could include task or team skills training, improving the organization’s communication infrastructure, or providing timely and accurate information to the team. Smith-Jentsch et al. (2001) found positive training effects on similarity to an expert model, similarity to other trainees, and consistency. Conversely, CannonBowers and Salas (2001) suggested that fully formed mental models are resistant to change and that mental models are most readily changed by demonstrating current model problems and how the model can be improved.

Swagak, Mulder, van Houten, and ter Hofte, (2000) research supports the validity of the idea that synchronous settings are better for reaching a shared understanding and are better for exchanging information. Groupware (www.whatis.com) can help people work together collectively while located remotely from each other and can include the sharing of calendars, collective writing, e-mail handling, shared database access, electronic meetings with each person able to see and display information to others, and other activities. With the invention of groupware, people expect to communicate easily with each other and accomplish difficult work even though they are remotely located. Groups with common ground, loosely coupled work, and readiness to use collaborative technology, have a chance at succeeding with remote work (Olson & Olson, 2000).

3.5 Increasing the Degree of Similarity of Team Members’ Mental Models

As stated earlier, the team has developed a TMM when there is some inherent degree of similarity or overlap that exists among the mental models of individual team members. Thus, movement or change towards similarity or overlap needs to begin to occur at least sometime during phase two. Some way of ascertaining overlap needs to be established and is discussed in more detail later in the Measurement section. It is

sufficient at this stage, to mention that there is a problem in specifying the optimal degree of overlap among team members (Cannon-Bowers & Salas, 2001). Generally speaking, most researchers agree that a major benefit of teamwork is that team members are able to bring multiple perspectives to bear on the problem at hand. However, a high degree of overlap could be likened to “groupthink” (Janis, 1972) in which the desire to maintain team cohesion is awarded priority over the decision-making process and the evaluation of divergent viewpoints becomes neglected (Cannon-Bowers et al., 1993). Team cohesion would differ by team type, for example military teams require a high degree of cohesion while design teams in industry would require a loose degree of cohesion. Too little shared knowledge could lead to poor coordination, thus reducing the team’s ability to adapt to changing environmental demands (Cannon-Bowers et al., 1993). There is some agreement that broader distributions of knowledge are beneficial to teams that operate in particular environments, such as when the jobs of team members are homogenous rather than divisible and when the status differences between team members are small rather than large. It is probably the case that the optimal distribution of knowledge, that is, mental model overlap varies according to the team task situation, or that different kinds of knowledge may be optimally distributed in the team in different ways (Heffner, 1998). Unfortunately, little is known about the dynamics of optimally distributed knowledge in teams (Kraiger & Wenzel, 1997).

3.6 Converging Mental Models of Team Members

One of the common presumptions in the literature is that member mental models will converge over time and that increased intra-team interaction will make this convergence process more rapid (Clark & Brennan, 1991; Levesque et al., 2001; Moreland, 1999; Rentsch & Hall, 1994). Certainly, there are indications that team members develop a more accurate and shared mental model of their fellow team members’ understanding over time (Liang, Moreland, & Argote, 1995). Jeffery (1999) showed support for the idea that mental models converge over time, based on team members’ self-perception. However, it was not clear whether convergence between a team mental model and an expert mental model occurred through team interaction or through individual education and training. The study highlights some of the difficulties associated with TMM research. The time frame of true TMM convergence may be longer. Using university samples has several risks such as less interaction, involvement, and investment than may be seen in real-world work teams. University samples are often tied to semester-long subjects, which may not provide sufficient scope for convergence. Finally, because each team is made up of

multiple members, study sample sizes may have to be quite large to register significant effects.

One implication of greater TMM congruence is that it is more likely to be correct or at least indicative of the most correct view of any of the group members. Such a view places quality (accuracy and efficiency) of the mental model as more important than similarity. However, this is not always the case as demonstrated by groupthink, where similarity may discourage critical thinking and lead to an incomplete and flawed mental model (Janis, 1972).

3.7 Phase 3—Fluent Performance or Expert Team Mental Models

In this high performance third phase, operations and interactions are smooth, people are comfortable in roles, a thorough understanding of other people's strengths, weaknesses, and role within-group is attained, and the transactional team work style wastes less resources and is better coordinated. Performance is thought to become relatively automatic but we suggest continues to improve through refinement of the production rule—the “how to” rules learned in phase two. In an organization, this would consist of negotiating the various routes and gates that would apply to knowing “how things get done around here.” The expert phase (eTMM) is reached when the individual and the team is able to make abstractions across various representations.

At this phase, team members should be able to recognize patterns of behavior and retrieve old knowledge and might also be able to make predictions about team work outcomes. That is, individually and as a team, they are able to run a mental model of the team task and visualize the solution and outcome.

3.8 Member-Supervisor/Manager Team Mental Models

Although we always imagine that the supervisor or facilitator fulfils the role of expert, Edelson (2000) tested the assumption that work group performance can be improved when member and supervisor mental models are more similar. The study found that, although work-group effectiveness was improved by members sharing mental models, it did not matter if the members' shared mental model was similar to the supervisor's mental model. Thus, it needs to be established prior to testing members' mental models, the nature of the expert TMM. The beneficial consequences of expert team mental models are clear (i.e., skilled team performance), but as Cannon-Bowers & Salas (2001) proposed there are multiple levels of shared cognition, each of which can be viewed as relating to expertise and a performance continuum. In relation to task-specific knowledge team members should have a shared and accurate understanding of the task

requirements, their role within the team and the norms, processes, and requirements specific to the team. Thus, an expert team will have mental models that are shared on multiple levels, not all of which would be necessary for the label of expert TMM. The key to the development of the expert TMM is performance outcomes and seamless interaction (see Edmondson, 1997). Some of this expertise is in the individuals, some is specific to the task, and some is specific to the constellation of individuals that comprises the team.

There has been much written about high performance teams. Some of the features suggested by Blinn (1996) to characterize high performance teams include a common focus, clearly defined roles, utilizing internal and external resources, being supportive of diversity, having good conflict resolution mechanisms, effectively using feedback, using less communication for task processes, and successfully managing time and meetings. Similarly, Margerison and McCann (1984) outlined the principles involved in high performance work teams. Phase 3 in a teams' acquisition of a TMM is when true performance gains can be attained. Thus, there is a need to know how dimensions of TMMs and the notion of an expert TMM relates to enhanced performance by elucidating causal pathways. The present work should aid in this development.

4 CONCLUSIONS

4.1 Future Research and Development

The extension of the mental model construct from shared cognition (i.e., shared and team mental models) appears to be a useful heuristic for interpreting the complexity of team functioning in the hurly-burly of modern-day organizations. However, there is little theoretical work on team mental models (Klimoski & Mohammed, 1994) and little empirical work in organizations, such as in shared cognition in shop-floor teams (see e.g., Langan-Fox, Waycott, Morizzi, & MacDonald, 1998) or in nonmilitary environments. Future research could examine the effect of new types of team formation and interaction on the nature of a team's mental model. For example, how virtual teams that often use asynchronous, technologically mediated communication tools achieve TMMs. What types of collaborative tools and team member skills maximize the creation of TMMs, especially when face-to-face contact may be limited? More reliable and valid measures of TMMs need to be developed. At present, there are many overlapping theoretical constructs but little cross-fertilization (Mohammed & Dumville, 2001). In addition, the degree to which a team's mental model spans across both knowledge and belief structure domains should be incorporated as a relevant criterion variable in research.

Research should be carried out in natural settings examining the work of, for instance, emergency center crews (Artman & Waern, 1999), air traffic control teams (Mackay, 2000), groups of planners and schedulers (Jackson, MacCarthy, & Wilson, 2004) and railway controllers and signallers. Wilson et al. (2001) has identified a number of roles that must be filled by such teams. These roles include being collaborating actors in a distributed cognitive network; showing mutual and peripheral awareness of each others' activities; acting as a hub and filter for formal information handling and as a link and net for informal information handling and as a balance and valve for decision making; being testers of systems or boundary pushers, rule sifters and knowledgeable (selective) rule followers, and demand managers. Better understanding of TMMs will assist in the design of tasks, jobs, and interfaces to support all these roles.

If we are to better understand the notion of TMMs and utilize that understanding in design, implementation, and management of teams in the future then we must address a number of basic questions to do with conceptualization and measurement. For instance, can we ever truly represent and describe a TMM or can we merely differentiate between performance of different teams? Alternatively, if we cannot describe a full mental model then we may be able to find ways of describing aspects of one. Related to this is the issue of bias in measurement, whereby there can be a certain circularity in mental model identification; the very type of experiment set up by researchers will determine the type of data and therefore what can be done with such data in analysis and interpretation. Thus, the way the mental model is represented is a function of the experimental paradigm used rather than any true translation of the mental model. An interesting question relevant for individual performance, but even more so for teams, is of the relationship between team mental model and team or shared situation awareness. Are both conceptual constructs required and to what extent do they overlap?

In a parallel with flaws in expert knowledge elicitation, is there any validity in the idea that the knowledge and beliefs and attitudes that underpin team mental models that can be identified and examined are, by definition, the least interesting or indeed least important to the building of a TMM? That is, there is the idea that the notions which really underpin skilled performance, and which presumably underpin mental models, whether team or individual, is not easily amenable to acquisition by researchers.

To overcome these many challenges in the TMM concept it would be desirable for researchers and practitioners to engage in an iterative feedback cycle between method, theory, empirical observation, and application. Through the

attempt to operationalize TMMs, the value of particular theoretical conceptions of TMMs can be assessed. Improved measurement models also lead to an improved capacity for researchers to explore the relationships between other relevant team variables and TMMs. More empirical research would refine our understanding of what features of TMMs are desirable and answer the important question of how TMMs relate to performance. One overall aim of this enterprise would be to have the tools and theory to aid the design of effective systems and programs to assist teams in achieving superior performance.

5 REFERENCES

- Ackerman, P.L. (1988). Determinants of individual differences during skill acquisition: Cognitive abilities and information processing. *Journal of Experimental Psychology: General*, 117(3), 288–318.
- Anderson, J.R. (1982). Acquisition of cognitive skill. *Psychological Review*, 89, 369–406. Anderson, J.R. (1993). *Rules of the mind*. Hillsdale, NJ: Erlbaum.
- Annett, J., & Duncan, K.D. (1967). Task analysis and training design. *Occupational Psychology*, 41, 211–221.
- Artman, H., & Waern, Y. (1999). Distributed cognition in an emergency coordination centre. *Cognition Technology and Work*, 1, 237–246.
- Banks, A.P., & Millward, L.J. (2000). Running shared mental models as a distributed cognitive process. *British Journal of Psychology*, 91(4), 513–531.
- Blessing, S.B., & Anderson, J.R. (1996). How people learn to skip steps. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, 22, 576–598.
- Blinn, C.K. (1996, Nov.–Dec.). Developing high performance teams. *Online*, 20(6), 56(1). Retrieved from <http://www.coachcaral.com/articles.html>.
- Bristol, N. (2004). Shared mental models: Conceptualization and measurement. Unpublished Ph.D. thesis. University of Nottingham.
- Cannon-Bowers, J.A., & Salas, E. (2001). Reflections on shared cognition. *Journal of Organizational Behavior*, 22, 195–202.
- Cannon-Bowers, J.A., Salas, E., & Converse, S. (1993). Shared mental models in expert team decision making. In N.J. Castellan, Jr. (Ed.), *Individual and team decision making* (pp. 221–246). Mahwah, NJ: Erlbaum.
- Carley, K.M. (1997). Extracting team mental models through textual analysis. *Journal of Organizational Behavior [Special Issue]*, 18, 533–558.
- Clark, H.H., & Brennan, S.E. (1991). Grounding in communication. In L.B. Resnick, R.M. Levine, & S.D. Teasley (Eds.), *Perspectives on socially shared cognition*. Washington, DC: American Psychological Association.
- Converse, S.A., Cannon-Bowers, J.A., & Salas, E. (1991). Team member shared mental models: A theory and some methodological issues. *Proceedings of the Human Factors Society 35th Annual Meeting* (pp. 1417–1421). Santa Monica, CA: Human Factors and Ergonomics Society.
- Cooke, N.J., Salas, E., Cannon-Bowers, J.A., & Stout, R.A. (2000). Measuring team knowledge. *Human Factors*, 42, 151–173.
- Edelson, R.E. (2000). The influence of supervisor-subordinate mental model congruence on group effectiveness and subordinates' satisfaction with their supervisor. *Dissertation Abstracts International, Section A: Humanities & Social Sciences*, 60(12-A), 4503.
- Edmondson, A.C. (1997). Group and organizational influences on team learning. Unpublished manuscript, Harvard University, Boston, MA.
- Edwards, A., & Wilson, J.R. (2004). *Implementing virtual teams: A guide to organizational and human factors*. Aldershot, UK: Gower.
- Ford, D.N., & Sterman, J.D. (1998). Expert knowledge elicitation to improve formal and mental models. *System Dynamics Review*, 14(4), 309–340.
- Genaidy, A., Karwowski, W., Succop, P., Kwon, Y-G., & Alhemoud, A. (2000). A classification system for characterization of physical and non-physical work factors. *International Journal of Occupational Safety and Ergonomics*, 6(4), 535–555.
- Gibson, C.B. (2001). From knowledge accumulation to accommodation: Cycles of collective cognition in work groups. *Journal of Organizational Behavior*, 22, 121–134.
- Gore, B.F. (2002). Human performance cognitive-behavioral modeling: A benefit for occupational safety. *International Journal of Occupational Safety and Ergonomics*, 8(3), 339–351.
- Heffner, T.S. (1998). Training teams: The impact of task and team skills training on the relationship between mental models and team performance. Unpublished manuscript, Pennsylvania State University, University Park, PA.
- Hollnagel, E. (1997, August). Building joint cognitive systems: A case of horses for courses? In G. Salvendy, M. Smith, & R. Koubek (Eds.), *Design of computing systems: Social and ergonomic considerations* (pp. 39–42). Amsterdam: Elsevier.

- Hollnagel, E. (2003). *Handbook of cognitive task design*. Mahwah, NJ: Erlbaum.
- Houghton, S.M., Simon, M., Aquino, K., & Goldberg, C.B. (2000). No safety in numbers: Persistence of biases and their effects on team risk perception and team decision making. *Group & Organization Management*, 25(4), 325–353.
- Jackson, S., MacCarthy, B.L., & Wilson, J.R. (2004). A new model of scheduling in manufacturing: Tasks, roles and monitoring. Accepted to appear in *Human Factors*, 46.
- Janis, I.L. (1972). *Victims of groupthink*. Boston: Houghton-Mifflin.
- Jeffery, Jr. (1999). Construct validation of shared mental models: An examination of knowledge structure convergence among team members in a decision-making simulation. Unpublished manuscript, University of South Alabama, Mobile, AL.
- Katzenbach, J.R., & Smith, D.K. (1993, March/April). The discipline of teams. *Harvard Business Review*, 21–35.
- Kay, D.S., & Black, J.B. (1990). Knowledge transformations during the acquisition of computer expertise. In S.P. Robertson, W.W. Zachary, & J.B. Black (Eds.), *Cognition, computing, and cooperation* (pp. 268–303). Norwood, NJ: Ablex.
- Klein, G. (1997). An overview of naturalistic decision making applications. In C.E. Zsombok & G. Klein (Eds.), *Naturalistic decision making expertise: Research and applications* (pp. 49–59). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Klein, G. (2000). Cognitive task analysis of teams. In J.M. Schraagen & S.F. Chipman (Eds.), *Cognitive task analysis* (pp. 417–429). Mahwah, NJ: Erlbaum.
- Klimoski, R., & Mohammed, S. (1994). Team mental model: Construct or metaphor? *Journal of Management*, 20, 403–437.
- Knaeuper, A., & Rouse, W.B. (1985). A rule based model of human problem solving in dynamic environments. *IEEE Transactions on Systems, Man and Cybernetics*, SMC-15, 708–719.
- Kraiger, K., & Wenzel, L.H. (1997). Conceptual development and empirical evaluation of measures of shared mental models as indicators of team effectiveness. In M.T. Brannick & E. Salas (Eds.), *Team performance assessment and measurement: Theory, methods, and applications*. Series in Applied Psychology (pp. 63–84). Mahwah, NJ: Erlbaum.
- Langan-Fox, J. (2001). Communication in organizations: Speed, diversity, networks and influence on organizational effectiveness, human health and relationships (Chap. 6). In N. Anderson, D.S. Ones, H.K. Sinangil, & C. Viswesvaren (Eds.), *International handbook of work and organizational psychology* (Vol. 2, pp. 188–205). London: Sage Publications.
- Langan-Fox, J. (2003). Skill Acquisition and the Development of the Team Mental Model: An integrative approach to analysing organizational teams. Ch. 12. Task and context. In M. West, D. Tjosvold, & K.G. Smith (Eds.), *International handbook of organizational teamwork and co-operative working* (pp. 321–360). London: Wiley.
- Langan-Fox, J., Armstrong, K., Anglim, J., & Balvin, N. (2002) Process in skill acquisition: Motivation, interruptions, memory, affective states and metacognition. *Australian Psychologist*, 37(2), 104–117.
- Langan-Fox, J., Code, S., Gray, R., & Langfield-Smith, K. (2002) Support for employee participation: Attitudes and perceptions in trainees, employees and teams. *Group Processes and Intergroup Relations*, 5(1) 53–82
- Langan-Fox, J., Code, S., & Langfield-Smith, K. (2000). Team mental models: Methods, techniques and applications. *Human Factors*, 42(2), 1–30.
- Langan-Fox, J., Waycott, J.L., & Albert, K. (2000). Linear and graphic advance organizers: Properties and processing. *International Journal of Cognitive Ergonomics*, 4(1), 19–34.
- Langan-Fox, J., Waycott, J., & Galna, C. (1997). Ability performance relations during skill acquisition. *Australian Psychologist*, 32 (3), 153–158.
- Langan-Fox, J., Waycott, J., Morizzi, M., & McDonald, L. (1998). Predictors of participation in performance appraisal: A voluntary system in a blue collar work environment. *International Journal of Selection and Assessment*, 6(4) 249–260.
- Langan-Fox, J., Wirth, A., Code, S., Langfield-Smith, K., & Wirth, A. (2001). Analysing shared and team mental models. *International Journal of Industrial Ergonomics*, 28, 99–112.
- Levesque, L.L., Wilson, J.M., & Wholey, D.R. (2001). Cognitive divergence and shared mental models in software development project teams. Shared cognition [Special Issue]. *Journal of Organizational Behavior*, 22, 135–44.
- Levine, J.M., & Moreland, R.L. (1991). Culture and socialization in work teams. In L.B. Resnick, J.M. Levine, & S.D. Teasley (Eds.), *Perspectives on socially shared cognition*. (pp. 257– 282). Washington, DC: American Psychological Association.
- Liang, D.W., Moreland, R.L., & Argote, L. (1995). Group versus individual training and group performance: The mediating role of transactive memory. *Personality and Social Psychology*, 21, 384–393.
- Mackay, W. (2000). Is paper safer? The role of flight strips in air traffic control. *ACM Transactions on Computer Human Interaction*, 6, 311–340.
- Margerison, C., & McCann, D. (1984). High performing managerial teams. *Leadership & Organization Development Journal*, 5(5), 9–13.
- Marks, M.A. (1998). Creating adaptive teams: Investigating antecedents of effective team performance in dynamic environments. Unpublished manuscript, George Mason University, Fairfax, VA. Mohammed, S., & Dumville, B.C. (2001). Team mental models in a team knowledge framework: Expanding theory and measurement across disciplinary boundaries. Shared cognition [Special Issue]. *Journal of Organizational Behavior*, 22, 89–106.

- Mohrman, S.A., Cohen, S.G., & Mohrman, A.M. (1995). Designing team-based organizations: New forms for knowledge work. San Francisco: Jossey-Bass.
- Mohrman, S.A. (1993). Integrating roles and structure in the lateral organization. In J.R. Galbraith & E. Lawler, III (Eds.), *Organizing for the future* (pp. 109–141). San Francisco: Jossey-Bass.
- Moreland, R.L. (1999). Transactive memory: Learning who knows what in work groups and organizations. In L.L. Levine, J.M. Messick, & M. Thompson (Eds.), *Shared cognition in organizations: The management of knowledge* (pp. 3–31). Mahwah, NJ: Erlbaum.
- Morris, N.M., & Rouse, W.B. (1985). The effects of type of knowledge upon human problem solving in a process control task. *IEEE Transactions on Systems, Man and Cybernetics*, SMC-15, 698–707.
- Neck, C.P., Connerley, M.L., & Manz, C.C. (1997). Toward a continuum of self-managing team development. In M.M. Beyerlein & D.A. Johnson (Eds.), *Advances in interdisciplinary studies of work teams* (vol. 4, pp. 193–216). Stamford, CT: JAI Press.
- Nonaka, I. (1994). A dynamic theory of organizational knowledge creation. *Organization Science*, 5, 14–37.
- Norman, D.A. (1983). Some observations on mental models. In D. Genter & A.L. Stevens (Eds.), *Mental models*. Mahwah, NJ: Erlbaum.
- Olson, G.M., & Olson, J.S. (2000). Distance matters. *Human-computer interaction. New agendas for human-computer interaction* [Special Issue], 15(2–3), 139–178.
- Patrick, J. (1992). *Training: Research and practice*. London: Academic Press.
- Rentsch, J.R., & Hall, R.J. (1994). Members of great teams think alike: A model of team effectiveness and schema similarity among team members. In M. Byerlein & D. Johnson (Eds.), *Advances in interdisciplinary studies of work teams*, Vol. 1, *Series of self-managed work teams* (pp. 22–34). Stamford, CT: JAI Press.
- Roschelle, J. (1996). Designing for cognitive communication: Epistemic fidelity or mediating collaborative enquiry? In D.L. Day & D.K. Kovacks (Eds.), *Computers, communication and mental models* (pp. 15–27). Philadelphia, PA: Taylor & Francis.
- Rouse, W.B., Cannon-Bowers, J.A., & Salas, E. (1992). The role of mental models in team performance in complex systems. *IEEE Transactions on Systems, Man and Cybernetics*, 22, 1296–1308.
- Rouse, W.B., & Morris, N.M. (1986). On looking into the black box: Prospects and limits in the search for mental models. *Psychological Bulletin*, 100, 349–363.
- Rutherford, A., & Wilson, J.R. (1991). A dialogue on mental models. In M.J. Tauber & D. Ackerman (Eds.), *Mental models and human-computer interaction* (pp. 39–58). Amsterdam: NorthHolland.
- Schendel, D. (1996). Knowledge and the firm. *Strategic Management Journal*, 17, 1–4.
- Sheperd, A. (1985). An improved tabular format for task analysis. *Journal of Occupational Psychology*, 49, 93–104.
- Smith-Jentsch, K.A., Campbell, G.E., Milanovich, D.M., & Reynolds, A.M. (2001). Measuring teamwork mental models to support training needs assessment, development, and evaluation: Two empirical studies. *Shared cognition* [Special Issue]. *Journal of Organizational Behavior*, 22, 179–194.
- Spender, J.C., & Grant, R. (1996). Knowledge and the firm: An overview. *Strategic Management Journal*, 17, 5–9.
- Staw, B.M. (1991). Dressing up like an organization: When psychological theories can explain organizational action. *Journal of Management*, 17(4), 805–819.
- Swaak, J., Mulder, I., van Houten, Y., & ter Hofte, H. (2000). Do ICT developments match with the needs of members of project teams? A study on synchronous and asynchronous interactions: Reasons and problems/Sluiten ICT-ontwikkelingen aan bij de behoeften van projectwerkers? *Onderzoek naar synchrone en asynchrone interacties: Redenen en problemen. Gedrag en Organisatie*, 13(6), 327–343.
- Tuckman, B.W. (1965). Developmental sequences in small groups. *Psychological Bulletin*, 63, 384–399.
- Tuckman, B.W., & Jensen, M.A.C. (1977). Stages of small group development revisited. *Group and Organizational Studies*, 2, 419–427.
- Van Heusden, A.R. (1980). Human prediction of third-order autoregressive time series. *IEEE Transactions on Systems, Man, and Cybernetics*, SMC-10, 38–43.
- Walsh, J.P., Henderson, C.M., & Deighton, J. (1988). Negotiated belief structures and decision performance: An empirical investigation. *Organizational Behavior and Human Decision Processes*, 42(2), 194–216.
- Wilson, J.R. (2000). Mental models. In W. Karwowski (Ed.), *International encyclopedia of ergonomics and human factors* (pp. 493–496). Taylor and Francis: London.
- Wilson, J.R., Cordiner, L.A., Nichols, S.C., Norton, L., Bristol, N., Clarke, T., & Roberts, S. (2001). On the right track: Systematic implementation of ergonomics in railway network control. *Cognition, Technology and Work*, 3, 238–252.
- Wilson, J.R., & Rutherford, A. (1989). Mental models. *Human Factors*, 31, 617–634.
- Wilson, J.R., & Whittington, C. (2001). Implementation of self managed teams in manufacturing: More of a marathon than a sprint. *AI and Society*, 15, 58–81.
- Zolnierczyk-Zreda, D. (2000). Modification of pathological type a as worksite stress management and disease prevention intervention. *International Journal of Occupational Safety and Ergonomics*, 6(2), 169–188.