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Differentiating knowledge in teams: The effect of shared declarative and procedural knowledge on team performance

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Abstract

The relative effect of sharing mental models (typically defined as declarative knowledge structures) and sharing procedural knowledge on team process and performance were assessed. Forty-eight students completed a series of missions as two person teams using a PC based tank simulation. The results showed some support for earlier findings that shared and accurate mental models of the task were related to team process which was related to team performance. In contrast, shared procedural knowledge was negatively related to team performance. Accurate procedural knowledge was positively related to team performance. Results are discussed in terms of the effect of sharing knowledge in teams on performance, and the implications for team training.

Differentiating knowledge in teams: The effect of shared declarative and procedural knowledge on team performance

Introduction

The organization of knowledge in teams is widely acknowledged to be a key factor in determining team performance, particularly knowledge that is organized within teams as 'shared mental models' (SMMs) (e.g. Cannon-Bowers, Salas & Converse, 1993; Klimoski & Mohammed, 1994; Mohammed & Dumville, 2001). This paper will seek to explore further the relationship between the organization of knowledge in teams and team performance by differentiating between declarative and procedural knowledge. We will argue that the benefits of sharing knowledge in the form of mental models have typically been demonstrated with declarative knowledge, not procedural knowledge. We will further argue that whereas accurate procedural knowledge improves team performance, sharing procedural knowledge does not have a positive impact on team performance, contrary to previous assumptions. To test this hypothesis, this study will measure both shared declarative knowledge and shared procedural knowledge to investigate their relative contribution to team effectiveness.

Shared mental models refer to an organized understanding of knowledge that is shared by a team (Cannon-Bowers et al., 1993). It is proposed that the sharing or overlap of knowledge enhances the accuracy of team members' expectations of each others' needs. This in turn enables efficient coordination as team members anticipate each others' requirements and leads to superior team performance. A number of studies have investigated this hypothesis by directly eliciting the mental models held by the team members (e.g. Marks, Sabella, Burke & Zaccaro, 2002; Marks, Zaccaro & Mathieu, 2000; Mathieu, Heffner, Goodwin, Cannon-Bowers & Salas, 2005; Mathieu, Heffner, Goodwin, Salas & Cannon-Bowers, 2000; Smith-Jentsch, Mathieu & Kraiger, 2005; Stout, Cannon-Bowers, Salas & Milanovich, 1999). These papers demonstrate that a positive relationship exists between SMMs and team process and performance. Whilst this is an important finding, it has sometimes been generalised to the benefits of "shared prior knowledge" (Madhavan & Grover, 1998: 4) and is an important part of the evidence supporting the benefits of shared cognition (e.g. Cannon-Bowers & Salas, 2001). However, as will be demonstrated below, these studies have a narrower focus than this, largely testing declarative knowledge. But this is not the only form of knowledge that could influence team process and performance. It may well be inaccurate to generalise the findings about sharing one form of knowledge to all knowledge types.

Cooke, Salas, Cannon-Bowers & Stout (2000) propose that three types of knowledge can exist in mental models: declarative knowledge; procedural knowledge and strategic knowledge. Declarative knowledge is defined as 'the facts, figures, rules, relations and concepts in a task domain' (p.153); procedural knowledge is defined as 'the steps, procedures, sequences, and actions required for task performance' (p.153); strategic knowledge is defined as 'the overriding task strategies and knowledge of when they apply' (p.153). In contrast cognitive psychology studies using experimental and neuroimaging data find only two distinct forms of knowledge, declarative and procedural, as defined above (e.g. Cohen, 1984; Cohen & Squire, 1980; Gabrieli, 1998). As this empirical work has not differentiated strategic knowledge as a separate type of knowledge, only two forms of long term knowledge will be investigated here, declarative and procedural. The effect of both of these on team performance will be investigated.

In contrast, most previous work has focused on only declarative knowledge in mental models. This has arisen implicitly, perhaps as a result of the definition of mental models that has been adopted. The most widely cited definition of a mental model in this literature is Rouse & Morris (1986) (e.g. Blickensderfer, Cannon-Bowers & Salas, 1997; Cannon-Bowers et al., 1993; Marks et al., 2000; Mathieu et al., 2000, Peterson, Mitchell, Thompson & Burr, 2000). They propose that a mental model is a 'mechanism whereby humans generate descriptions of system purpose and form, explanations of system functioning and observed system states, and predictions of future system states' (Rouse & Morris, 1986: 360). This definition does not refer to procedures that are used to complete the task. It only refers to knowledge of what constitutes the system and the relationships between different aspects of it. In other words, it defines a mental model as a declarative knowledge structure, not containing procedural knowledge. Other frequently cited definitions of mental models are also clearly declarative knowledge structures (e.g. Johnson-Laird, 1983; Moray, 1997).

Rouse & Morris's definition has also informed methods of eliciting mental models. Most studies have measured mental models by asking participants to rate the relationship between attributes of the task and team (Marks et al., 2002; Mathieu et al., 2005; Mathieu et al., 2000; Stout et al., 1999). This adequately measures declarative knowledge of the relations between elements of the mental model, but does not elicit procedural knowledge of how the task is completed. Only one study elicited procedural knowledge of how the task was completed, Marks et al. (2000). Thus the majority of studies that test 'shared mental models' are referring to the sharing of declarative knowledge structures, both theoretically and methodologically, even though this is frequently not made explicit. To clarify the usage of terms in this paper we will make this distinction explicit. 'Shared mental models' will be used to refer to the overlap of mental models holding only declarative knowledge, as defined by Rouse and

Morris, and other mental model theorists such as Johnson-Laird (1983) and Moray (1997) and as used in the empirical studies of Marks et al. (2002); Mathieu et al. (2005); Mathieu et al. (2000) and Stout et al. (1999). The term 'shared procedural knowledge' will be used to refer to the overlap of procedural knowledge amongst team members.

One outcome previous work not distinguishing between declarative and procedural knowledge is that the relative impact of the accuracy of these two forms of knowledge on team performance is not known. Another theoretical concern is that the implications of sharing procedural knowledge have not been fully considered. As procedural knowledge differs from declarative knowledge in a number of ways, it is not necessarily the case that sharing procedural knowledge has the same effect on team process and performance as sharing declarative knowledge. We argue that the current theory concerning the benefits of SMMs is valid for declarative knowledge but does not generalise to procedural knowledge. The theoretical differences between sharing declarative knowledge and sharing procedural knowledge can be highlighted by examining how they are proposed to impact on team performance.

The initial theoretical work proposing the benefits of SMMs also cited the Rouse & Morris definition of mental models (Cannon-Bowers et al., 1993) and so emphasised sharing descriptions, explanations and predictions rather than procedures. Therefore, the enhanced expectations that SMMs were predicted to afford were the result of sharing declarative knowledge rather than procedural knowledge. Examining the proposed usage of shared mental models illustrates this, and the following is a prototypical example. In a given situation one team member will infer his or her requirements using a mental model to either understand the situation or use the mental model to predict what will happen next. This may lead to the conclusion that a certain piece of information is required. A second team member who has the same (or a compatible) mental model will form the same (or a compatible) understanding or prediction, and infer that the first team member requires this information. He or she then knows to provide this information, without it being requested. The similarity of the mental models leads them to draw the same inferences about the first team member's needs. Crucially, it is the similarity of these inferences that ensure the expectations of the team members are similar which leads directly to the improved coordination and team performance. Hence improved team performance follows from sharing mental models.

We propose that procedural knowledge, in contrast, does not require team members to draw inferences about each others' needs. Knowledge of the procedure for a task simply concerns what to do in any given situation. In the above example, the second team member would recognise the situation from various cues and know what information must be supplied in those circumstances. In order to do this it is not necessary to infer *why* this information is necessary, as is suggested in the SMMs illustration. This means that team members do *not* need to form similar inferences about the task in order to predict each others' needs. Therefore, the requirement to have similar knowledge in order to make similar inferences is removed. Instead, the procedural knowledge that team members need to know in order to perform effectively is simply determined by their role. They must know what to do in the situations that they will encounter, including knowing how to interact with their team members. If team members have similar roles then they may well develop similar procedural knowledge in response to similar task demands. But if they occupy different roles they will develop different procedural knowledge; it would be less efficient to develop knowledge about procedures for which they have no use. Hence there is little utility in shared procedural knowledge *per se*; it will only arise where there is an overlap in roles.

Unfortunately, the one study that elicits procedural knowledge in teams does not test this hypothesis effectively (Marks et al. 2000). In order to test whether procedural knowledge must be shared it is necessary to use a task in which the roles within the team have few similarities. If the team roles are similar, shared procedural knowledge may arise simply as a result of team members learning to complete similar tasks, as described above. It is then not possible to distinguish if shared procedural knowledge is associated with effective team performance because of sharing or because team members have simply learnt to do the same task. Marks et al's study involved some differences of role, but also many similarities; all team members were required to drive a tank, find the enemy and so forth. A greater separation of roles is required to test the hypothesis we have outlined here. Secondly, the method of eliciting knowledge used by Marks et al. was not ideal as it strongly encouraged shared knowledge to develop. The same set of concepts was given to all participants to use (they could not generate their own). Each team member was explicitly asked to generate the procedures used by other team members as well as their own before the task began and in between trials. This ensured that they focused on other team members' procedures frequently during the experiment. It is possible that this requirement encouraged them to learn others' procedural knowledge as a result of repeated eliciting of the knowledge rather than because of the task. In order to test the role of shared procedural knowledge in team performance a study is required that uses different roles for the team members, elicits procedural knowledge using a method that does not contaminate team performance or later measurement of knowledge and does not force team members to describe each others' procedural knowledge. This study will elicit procedural knowledge using a task and measure with these advantages and also elicit declarative knowledge with a typical measure of mental models. The relationship between this knowledge and team process and performance will then be established.

Shared knowledge, team process and team performance

SMMs research has typically been analysed using an input-process-output framework (e.g. Hackman, 1987). SMMs are viewed as an input, team process as the communication and coordination etc. of the team, and level of performance on the task as output. The relationship between input and output is predicted to be mediated by team process. This study will seek to add shared procedural knowledge to the existing framework by regarding it as an input.

If procedural knowledge and declarative knowledge are to be differentiated as different forms of knowledge used by teams, it is important to demonstrate that they are not simply measuring the same underlying knowledge in different ways. If they are not, then the accuracy of the two forms of knowledge will not necessarily be related. This leads to the first hypothesis that accurate procedural knowledge and accurate SMMs will not be associated with each other (Hypothesis 1).

The I-P-O framework leads to a number of hypotheses. Those regarding SMMs will be considered first. Previous work has indicated that team members share more than one mental model. Of these, the most widely studied are mental models of the task and mental models of team (e.g. Mathieu et al. 2000). A further distinction that is drawn is between mental models that are shared and mental models that are accurate (e.g. Marks et al. 2000). It is important for mental models not only to be shared but also to be accurate. These two factors are potentially confounded because developing accurate mental models can lead to an increasing similarity of mental models if team members move towards a similar expert model. This may mean that sharing mental models can appear associated with superior team performance, when in fact it is the greater accuracy of the mental models rather than the sharing *per se*. To overcome this, the effects of sharing and accuracy of mental models will be partitioned statistically to create separate measures of sharing and accuracy. It is predicted that both sharing mental models of the team (Hypothesis 2a) and sharing mental models of the task (Hypothesis 2b) will be positively associated with team process and team performance. Similarly it is predicted that accurate mental models of the team (Hypothesis 3a) and accurate mental models of the task (Hypothesis 3b) will be positively associated with team process and team performance.

The expectations concerning shared procedural knowledge were discussed above. It was predicted that when teams had different roles in the task (as they do in this study) it would be more efficient for them only to retain procedural knowledge related to their own task, with the result that sharing procedural knowledge will be negatively associated with team process and team performance (Hypothesis 4). It was predicted that the most important factor concerning procedural knowledge is its accuracy. Hence accurate procedural knowledge will be positively associated with team process and team performance (Hypothesis 5). In line with previous SMM work and studies of teams within the I-P-O framework, it is predicted that team process will be positively associated with team performance (Hypothesis 6).

Method

Participants

Forty-eight undergraduate and postgraduate students from the University of Surrey volunteered to participate in the study. Their mean age was 25.13 years (SD = 2.76). Thirty-two participants were male and sixteen were female. Participants were randomly allocated to teams of two. They were paid ten pounds on completion of the experiment.

Task Apparatus

Teams played a PC based tank simulation called Steel Beasts (eSim games, 2000). The simulation depicted an M1A1 tank which the team jointly controlled. One team member controlled the tank's movement and the other team member controlled the tank's gun. Each team member had their own PC and joystick, linked via a local area network, presenting their view from the tank. These computers were adjacent to allow communication, but the screens were angled to prevent participants observing each others' monitor.

The teams' mission was to seek and destroy enemy tanks. Their approximate location was indicated on an onscreen map along with the current position of the participants' tank and the terrain. The terrain approximately simulated a rural European area with small hills, meadows, woods, rivers and some small villages. Each mission contained six enemy tanks and one point was awarded for each tank successfully destroyed within the twenty minute time limit. The missions were custom designed and piloted to avoid floor and ceiling effects and to ensure that all missions were of a similar level of difficulty. The task was highly interdependent. To perform effectively teams had to coordinate their actions in order to find enemy tanks quickly by both navigating towards them (the driver) and spotting them (both the driver and gunner). They then had to shoot them (the gunner) whilst taking appropriate cover to avoid being destroyed (the driver). These tasks had to be completed under the dynamic conditions and time pressure of return fire from the enemy, time limits on the task and varying terrain.

Measures

Performance. Teams completed three missions and were awarded one point for each enemy tank successfully destroyed. There were six enemy tanks in each mission, so the maximum possible score was eighteen.

Team Process. Team processes were rated by an observer who watched videotapes of all the experimental missions. Five items were used based on the Team Effectiveness Model (Tannenbaum, Beard & Salas, 1992). These were 'How effectively did they coordinate their actions?', 'How effectively did they communicate?', 'How effectively did they resolve conflicts?', 'How effectively did they make decisions?' and 'How effectively did they solve problems?'. Each item was rated using a five point scale that ranged from 1 (very ineffectively) to 5 (very effectively). These scores were summed to create an overall measure of team process. Cronbach's alpha for this scale was 0.92. One third of these were rated by a second independent observer to establish inter-rater reliability which was found to be significant ($r = 0.9$, $p < 0.0001$).

Mental Models. Task and team mental models were measured using a similar technique to Marks et al. (2002), Mathieu et al. (2000), Mathieu et al. (2005) & Stout et al. (1999).

Participants completed measures of task and team mental models individually by rating the perceived relationships between various attributes. Each measure listed the attributes along the top and side of a grid. Participants rated each attribute of the mental model in relation to all other attributes of that model using a 9 point scale ranging from -4 (a very strong negative relationship) to +4 (a very strong positive relationship). Task analysis based on expert users and technical documentation led to the identification of seven key task attributes: speed, night vision, range finding, map reading, finding enemy, shooting and steering. Seven key team attributes were taken from the measure used in Mathieu et al. (2000). These were: amount of information, quality of information, coordination of action, roles, liking, team spirit and cooperation.

The sharing of mental models was assessed using a Mantel test, a method that is widely used to assess the similarity between two matrices (especially in ecological studies) (c.f. Legendre, 2000; Mantel & Valand, 1970). This was applied to the matrix of comparisons collected for the mental model measure. Specifically, a partial Mantel test was used which tests the similarity between two matrices whilst controlling for the effect of a third. The third matrix was an expert rating of the relationships between the attributes in the measure, elicited from a subject matter expert. This was used to provide a measure of the similarity between the mental models of the two team members whilst controlling for the accuracy of their mental models. Secondly, the similarity between each individual's mental models and an expert mental model was calculated to provide a measure of mental model accuracy. The mean of these was used as a measure of mental model accuracy for the team.

Procedural knowledge. To assess procedural knowledge individuals were asked to write down any procedures that they used to complete the task, and the situations in which they were implemented. This took the form of a number of situation-action pairs. Under 'situation' they wrote the circumstances when they completed an action. Under 'action' they wrote what they did. Team members were not presented with set situations as this would have influenced which situations they reported. It would have been difficult to establish if procedures were genuinely shared or whether team members had simply produced a plausible answer to a situation they were asked about, but would not have otherwise considered important. Rather, they generated their own situations based on what they thought to be the most aspects of the tasks that required comment. They were asked to specify whether these procedures related to their own role, their team member or both. A task analysis was conducted to establish the key procedures. A hierarchical task analysis procedure was used to do this (Shepherd, 2001) in which each mission was broken down into individual enemies on route. For each of these encounters, sub tasks were identified for (a) locating the enemy e.g. visually or using the map (b) engaging the enemy e.g. shooting at them and (c) retreating. These three subtasks were then further subdivided into the procedures for completing each one, e.g. selecting weapon, aiming the gun, finding the range, firing the gun etc. Participants' procedures were coded to establish how many of these procedures were reported which was used as a measure of accuracy, and also the proportion of procedures that both team members reported which was used as a measure of shared procedural knowledge.

Procedure

Participants were randomly assigned to roles within the team and completed a questionnaire to record demographic information. The nature of the task was explained to them, and they began training on their respective tasks (driver or gunner). This took approximately half an hour, and involved the experimenter explaining the controls to each team member and supervising practice at driving or shooting respectively until the participants were competent at performing these skills. Teams then completed three missions as described above, each of which lasted twenty minutes. These were of similar difficulty and the order was counterbalanced across teams. Team members could communicate freely about any aspect of the task in order to avoid artificial constraints on the team process. They were not able to see each others' screens, however they could describe the view. After completing the third mission team members independently filled out the mental model and procedural knowledge questionnaires. The experiment took approximately two hours to complete.

Results

Hypothesis 1. Table 1 presents correlations and descriptive statistics for all of the variables. No significant correlation was found between the accuracy of procedural knowledge and the accuracy of the mental models. This suggests that the two measures were eliciting different forms of knowledge, supporting the distinction between procedural knowledge and mental models as declarative knowledge.

Further analyses were conducted using multilevel modelling (c.f. Snijders & Bosker, 1999). This technique was used because each team completed three trials. The data for these trials are not independent; they are grouped according to the team as a result of the repeated measures design. Rather than aggregate across these scores to create a single dependent variable at the level of the group, a multilevel model can be used to analyse the data at two levels, the level of the trial nested within the level of the team.

Hypothesis 2. Table 2 presents the results of the multilevel modelling of team process with team knowledge as predictors. SMMs of the team were not found to be significant predictors of team process ($t = 0.32$, $p>0.05$) and nor were SMMs of the task ($t = -0.84$, $p>0.05$). Table 3 presents the results of the multilevel modelling of team performance with team knowledge as predictors. SMMs of the team were not found to be significant predictors of team performance ($t = 1.78$, $p>0.05$) although the result did approach significance. SMMs of the task were not found to be significant predictors of team performance ($t = 0.95$, $p>0.05$).

Hypothesis 3. Accurate mental models of the team was a significant predictor of team process, ($t = 2.21$, $p <0.05$) but accurate mental models of the task were not ($t = 1.35$, $p>0.05$). Accurate mental models of the team were not a significant predictor of team performance ($t = -0.05$, $p>0.05$) and nor were accurate mental models of the task ($t = 0.80$, $p>0.05$).

Hypothesis 4. Shared procedural knowledge was not found to be a significant predictor of team process ($t = 0.24$, $p>0.05$), but it was found to have a significant negative association with team performance ($t = -2.23$, $p<0.05$). Therefore, the less procedural knowledge that was shared by a team, the better they performed.

Hypothesis 5. Accurate procedural knowledge was not found to be a significant predictor of team process ($t = 0.24$, $p>0.05$), but it was found to be a significant predictor of team performance ($t = 2.03$, $p<0.05$). Therefore, the more accurate procedural knowledge the team members held, the better they performed.

Hypothesis 6. Table 4 presents the results of the multilevel modelling of team performance with team process as a predictor. Team process was found to be an accurate predictor of team performance ($t = 3.21$, $p<0.001$). Therefore, the more effective the teams' process, the better they performed.

Discussion

The results of this study demonstrate the effects of procedural knowledge on team performance. Specifically, they show that accurate procedural knowledge is positively associated with team performance and that shared procedural knowledge is negatively associated with team performance. This finding is particularly interesting in the context of broader questions about the organization of knowledge in teams. The study also found a positive association between SMMs and team process and performance, but these findings are mixed as not all hypotheses were supported.

These results indicate that the focus on mental models, which are most frequently defined and measured as declarative knowledge, is too narrow; clearly procedural knowledge has a significant role in team performance as well. The non-significant correlations between the declarative and procedural knowledge measures suggest that they were eliciting different forms of knowledge, supporting the distinction between procedural knowledge and mental models as declarative knowledge. The results also demonstrate that mental models and procedural knowledge both account for some variance in performance independently. In other words, both declarative and procedural knowledge structures play distinct and complementary roles in determining team performance.

The negative association between shared procedural knowledge and performance is particularly interesting. There has been some debate about what must be shared in shared cognition (e.g. Cannon-Bowers & Salas, 2001). Whilst the SMMs literature has demonstrated the benefits of sharing mental models, especially in time pressured circumstances, the transactive memory literature has highlighted the benefits of distributing knowledge for recall (e.g. Moreland, 2000; Wegner, Erber, & Raymond, 1991). Some authors have advocated distributing mental models as long as the knowledge is divided into coherent modules (Banks & Millward, 2000). Previous empirical work had not sought to differentiate declarative and procedural knowledge, and so the optimal arrangement of procedural knowledge in teams had not been explicitly considered. This study supports the idea that whereas declarative mental models should be shared, it is most efficient and effective for team members to hold only the procedural knowledge relevant to their task. This means that if team members have distinct roles, it is optimal for them *not* to share procedural knowledge.

We suggest that this finding, which is the opposite to that normally found in studies of SMMs, is the result of how teams use procedural knowledge. It has not been found in previous studies of shared knowledge in teams because they have usually examined declarative knowledge. We argue that team members use procedural knowledge simply to recall how to act in various situations. Accounts of SMMs suggest that team members infer each others' requirements because they are using similar mental models. With procedural knowledge there is no need for them to infer why other team members have certain requirements; they simply learn what those requirements are in the appropriate situations. As a result they need not share knowledge of the task or team to draw similar inferences about their expectations. Knowledge will only be shared if team members have similar roles and so have learnt similar tasks. As team members' roles in this task were quite distinct, sharing procedural knowledge was not associated with effective team performance.

The I-P-O framework accounted for some but not all of the findings. Several previous findings concerning SMMs were replicated in this study. Accurate mental models of the team were significant predictors of team process and SMMs of the team approached significance as predictors of team performance. A shortcoming of this finding is that ratings of accuracy were generated by only one task expert (the first author) whereas multiple experts would have been more reliable, and indeed multiple correct mental models may exist (e.g. Mathieu et al., 2005).

The other hypotheses concerning SMMs were not as predicted and mental models of the task in particular did not fit the expected I-P-O framework. This pattern of mixed findings has been found in some previous studies, e.g. Mathieu et al. (2000), which this study sought to replicate most closely, and also Mathieu et al. (2005). This replication provides further evidence for a positive association between mental models and team process and performance, but confirms the pattern of earlier work suggesting that this is not always a strong effect. In particular, there was no relationship between sharing mental models and team process or performance after the accuracy of mental models was controlled for, however there was an effect of accuracy of mental models after sharing was controlled for. This result is not unique as it was also found by Edwards, Day, Arthur and Bell (2006). Earlier papers such as Mathieu et al. which found an effect of sharing mental models did not separately account for accuracy, and it is possible that these results arose not because mental models were shared *per se*, but because both team members were accurate (and so similar). Hence the findings of this paper support the role that has been suggested mental models play in influencing team performance, but add to the evidence that simply sharing mental models alone is not sufficient. They must be accurate.

Measuring procedural knowledge as a further input complements SMMs by explaining further variance in team performance, but it was not a significant predictor of team process and so these results are not fully reconcilable within an I-P-O framework.

The participants in this study were novice users of a low fidelity simulation of a tank, and formed teams for a very limited period of time. This is not a typical team situation and so it is necessary to consider the generalisability of the research. This approach to studying teams is a research strategy that has been found useful in many similar areas, e.g. Baker, Prince, Shrestha, Oser & Salas, (1993); Driskell & Salas (1992); Mathieu et al. (2000); Marks et al. (2002). This testing environment allowed for an appropriate level of controlled complexity in the task. The task was dynamic, time pressured, involved interdependence between the team members and was sufficiently complex to engage participants fully. However it is feasible to learn the task within a reasonable period of time, and it is possible to design missions with sufficient control that each team faces an appropriate challenge in order to test the hypotheses effectively. Therefore this approach allows for the necessary experimental control to allow adequate testing of theory whilst containing many elements of team work that are of interest. Whilst these results cannot be directly generalised to an actual tank crew because of the differences in the training of the participants, the physical environment of the simulation and so forth, it is possible to form conclusions about the role of knowledge sharing in performing dynamic tasks. These theoretical developments may then be generalised and further tested in more ecologically valid, but less experimentally controlled, conditions in order to fully appreciate the role of shared knowledge in team performance.

There are a number of areas of future research and applications suggested by this study. Chiefly, the two key findings concerning procedural knowledge would benefit from further work. Accurate procedural knowledge was found to be a significant predictor of team performance. Research on mental models has benefited from distinguishing between mental models of team and task, whereas this study did not elicit this knowledge separately. More could be learnt about the role of shared procedural knowledge by doing this. Further work has considered multiple expert solutions (Mathieu et al., 2005) and interactions between different areas of knowledge (Smith-Jentsch et al., 2005). Theories of skill acquisition suggest that procedural knowledge will develop over time and is a key feature of expert performance (e.g. Anderson, 1982; Taatgen & Anderson, 2002). Assessing the development of procedural knowledge would further illuminate this process. Previous work on the convergence of SMMs over time have either shown that there is no further convergence (e.g. Mathieu et al., 2000) or that mental models became less shared over time (Levesque, Wilson & Wholey, 2001). It may well be that the development of procedural knowledge is interacting with this process.

The negative association between shared procedural knowledge and team performance is also of interest in the context of the current preference for shared knowledge with SMMs. In particular, the findings do not explain the penalty for sharing procedural knowledge. If the roles differ then it might have been the case that the shared knowledge would be redundant rather than a hindrance. This would have meant that no relationship would have been found between shared procedural knowledge and performance. Given that a negative association was found however, it is important to understand why this occurred in order that teams do not acquire shared knowledge that is detrimental to their performance. Team training methods such as cross training are demonstrably effective in improving SMM and team performance(e.g. Marks et al, 2002; Volpe, Cannon-Bowers, Salas & Spector, 1996), but if this method also develops counterproductive shared procedural knowledge then its utility could be reduced. Understanding the role of shared procedural knowledge could enhance the benefits of cross training by developing shared of knowledge only where it is beneficial.

More generally, future research should consider whether sharing knowledge is always a good thing. This is an assumption of the contemporary knowledge management enterprise as one of the principle aims is to encourage knowledge sharing; to transform personal 'know how' into corporate property for intra-organizational dissemination and sharing (Brown & Duguid, 1998). 'Know-how' can be distinguished from 'know-what' as procedural and declarative knowledge respectively, the assumption being that the former is normally more implicit than the latter and hence more difficult to capture and share (Nonaka, 1994; Polanyi, 1966). Yet the findings here suggest that sharing procedural knowledge is not necessarily always a good thing. This may in part be due to the highly self-referential nature of procedural knowledge (Alvesson, 2001).

Acquired through personal practical experience, 'know-how' may not in fact be something that can or indeed should be shared since by definition, it denotes something that has been appropriated through active engagement with a task (Leach, Jackson & Wall, 2001). Without this active engagement as a process through which know-how can be appropriated, it may be rendered meaningless simply through the fact of making something fundamentally implicit, now explicit and hence somewhat de-contextualised. Thus it is possible to see how knowledge shared that has not otherwise been 'acquired' via a practical process of doing, feedback and reflection could actually detract from performance.

In conclusion, this study has investigated the impact of the organization of knowledge in teams on team process and performance. It sought to expand on previous work by investigating the role of sharing both procedural and declarative knowledge in determining team process and performance. Accurate procedural knowledge was found to be a strong predictor of team performance, and a negative association was found between shared procedural knowledge and team performance, that is, teams without shared procedural knowledge performed better. These findings complement SMMs, which were argued to be best understood as declarative knowledge structures. The study found mixed support for a positive association between SMM and team process and performance. Whilst SMMs are related to superior team performance, it was found that accurate and unshared procedural knowledge complemented this relationship and were also strongly related to team performance.

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Table 1

Variable Correlations and Descriptive Statistics for Procedural Knowledge (PK), Mental Models (SMM) and Shared Mental Models (SMM)

	1	2	3	4	5	6	7	8
1.Shared PK	-							
2.Accurate PK	0.40	-						
3.Team SMM	-0.25	0.01	-					
4.Task SMM	0.24	0.10	-0.35	-				
5. Team accurate MM	0.01	0.21	-0.20	0.39	-			
6. Task accurate MM	-0.07	0.16	0.10	-0.04	-0.18	-		
7. Team Process	-0.13	0.04	0.06	-0.07	0.36	0.22	-	
8.Performance	-0.38	0.37	0.42	-0.06	0.12	0.35	0.43	-
Mean	0.25	3.67	0.15	0.09	0.25	0.42	17.59	10.65
SD	0.23	1.47	0.32	0.23	0.15	0.23	6.02	3.45

Correlations >|0.41|, p<0.05

Table 2

Multilevel Model for Predictors of Team Process: Procedural Knowledge (PK), Mental Models (SMM) and Shared Mental Models (SMM)

Effect	Variance	ϒ coeffecient	SE	t	p
Fixed					
Intercept		12.16	3.99	3.05	<0.01
Shared PK		1.45	5.93	0.24	>0.05
Accurate PK		-0.72	0.91	-0.79	>0.05
Team SMM		1.23	3.85	0.32	>0.05
Task SMM		-4.79	5.73	-0.84	>0.05
Team accurate MM		19.56	8.85	2.21	<0.05
Task accurate MM		6.94	5.14	1.35	>0.05
Random					
Group mean, u_{0j}	25.91		8.16	3.18	<0.01
Level 1 effect, r_{ij}	5.17		1.08	4.80	<0.0001

Table 3

Multilevel Model for Predictors of Team Performance: Procedural Knowledge (PK), Mental Models (SMM) and Shared Mental Models (SMM)

Effect	Variance	ϒ coeffecient	SE	t	p
Fixed					
Intercept		2.37	0.67	3.45	<0.001
Shared PK		-2.29	1.03	-2.23	<0.05
Accurate PK		0.32	0.16	2.03	<0.05
Team SMM		1.18	0.67	1.78	>0.05
Task SMM		0.94	0.99	0.95	>0.05
Team accurate MM		-0.08	1.53	-0.05	>0.05
Task accurate MM		0.71	0.89	0.80	>0.05
Random					
Group mean, u_{0j}	0.22		0.27	0.80	>0.05
Level 1 effect, r_{ij}	1.81		0.38	4.79	<0.0001

Table 4

Multilevel Model for Team Process as a Predictor of Team Performance

Effect	Variance	ϒ coeffecient	SE	t	p
Fixed					
Intercept		1.59	0.63	2.52	<0.05
Process		0.11	0.03	3.21	<0.01
Random					
Group mean, u_{0j}	0.57		0.35	1.64	>0.05
Level 1 effect, r_{ij}	1.63		0.34	4.79	<0.0001