TOWARD UNDERSTANDING THE DYNAMIC RELATIONSHIP BETWEEN TEAM AND TASK SHARED MENTAL MODELS AS DETERMINANTS OF TEAM AND INDIVIDUAL PERFORMANCES

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ABSTRACT

The purpose of this research is to find a mechanism to ultimately enhance team and individual performance in team-based projects. While increasing numbers of research and practice upon teams and their development have studied the role of shared mental models in understanding team performance in the social-psychology literature, its utility through which team performance can be assessed in the management literature received mixed results. This study focused on understanding the dynamic relationship between shared mental models and performance over time. Specifically, this study investigated how the changes in Team and Task Shared Mental Models (Team-SMM and Task-SMM) affect team and individual performance of engineering students. The pairwise ratings and Likert-scale questionnaires were used to measure the Team-SMM and Task-SMM. Results indicated that Team-SMM and Task-SMM had their unique influences on team and individual performance, and their relationships varied depending on the task and team demands at the specific time period of the team project. Implications for managing team and individual performances are discussed.

Keywords: Team and Task Shared Mental Models, Team Performance, Individual Performance.

Background and Theoretical Framework

Teams are important and dynamic entities in performing educational as well as industrial settings. Several scholars argue that complex tasks can be better performed in the team level because team members have opportunities to share his or her expertise, motivate one another to achieve their given task and deal with ongoing changes effectively (e.g. Burke, Stagl, Salas, Pierce & Kendall, 2006; Ilgen, Hollenbeck, Johnson & Jundt, 2005). In working as a team, team performance is not only caused by a matter of individual cognition, but it is also supported through team cognition. Team cognition is a theoretical concept that illustrates cognitive processes in a team (Cooke, Kielke, Salas, & Stout, 2003). Specifically, the team cognition is working when team members are doing some cognitive activities together such as planning, decision making and solving problem (Cooke, Gorman, Myers, and Duran, 2011). Under the concept of team cognition, the majority of prior research has principally dealt with
shared mental models (Cannon-Bowers, Salas, & Converse, 1993; Cooke et al., 2003; Gibson, 2001). The term “shared mental models” is defined as a “knowledge structure held by members of a team that enables them to form accurate explanations and expectations for the task, and in turn, to coordinate their actions and adapt their behavior to demands of the task and other team members” (Cannon-Bowers, Salas, & Converse, 1993, p. 228). Based on Cannon-Bowers, Salas, and Converse’s (1993) classifications of shared mental models, Mathieu, Goodwin, Heffner, Salas, and Cannon-Bowers (2000) suggest that team-related (Team-SMM) and task-related mental models (Task-SMM) are types of shared mental models. Team-SMM refers to the team interaction mental model and team mental model while the Task-SMM includes the task mental model and equipment mental model (see Figure 1.). These two mental models (Team-SMM and Task-SMM) are also consistent with the idea that teams develop two tracks of behavior—a teamwork track and taskwork track (McIntyre & Salas, 1995).

Figure 1. Shared Mental Models: Team-SMM and Task-SMM


Shared mental models are believed to contribute to both team and individual performance (Cannon-Bowers, Salas, & Converse, 1993). Shared mental models are certainly interwoven with individual mental models that are closely associated with individual performance. While the individual’s mental model reflects the individual’s perception of reality (Brunswik, 1956), the shared mental model represents the team’s shared perception of reality. The shared mental model is built based on team members’ individual mental models but it is more than just a sum of individual mental models (Cooke et al, 2004). It is emerged intentionally or unintentionally through team dynamics. The individual mental models are
also affected by the shared mental model during team projects. Therefore, it is expected that individual performance as well as team performance will depend on how well team members build their shared mental model throughout their team project.

However, previous studies have shown mixed findings in the relationship between shared mental models (Team-SMM and Task-SMM) and team performance and which one of the shared mental models has the better predictive of team performance. For examples, Leversque, Wilson and Wholey (2001) found that team members with highly-shared Team-SMM performed significantly better, although this relationship was not found with Task-SMM. Mathieu, Heffner, Goodwin, Salas, and Cannon-Bowers (2000) found similarity among team members’ Team-SMM that was positively related to team performance. Likewise, Heffner (1998) also found that both of team members’ Task-SMM and Team-SMM 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. However, in a laboratory-based study, Mathieu et al. (2005) showed that Task-SMM similarity, not Team-SMM, was significantly related to both team processes and team performance. Resick (2004) also found that team performance was the outcome of Task-SMM, but it was not related to Team-SMM. Moreover, Lim and Klein (2006) found that both Team-SMM and Task-SMM positively influenced team performance.

Based on these mixed results, we recognized that Team-SMM and Task-SMM may not be equally effective predictors of performance, even though all these studies were not conducted in the same controlled situations in terms of the same population, the same research instrument, the same performance measurement. Thus, the existing results warrant supplemental studies to obtain a better understanding of the relationships between shared mental models (Team-SMM and Task-SMM) and performance. Moreover, having a shared mental model among team members is particularly important in manufacturing engineering education where team-based learning is an integral part of the learning curriculum and the learning tasks are based on complex real-world problems. In the manufacturing engineering context, the nature of tasks is complex and dynamic (Kelley, 2005; William, Diane, & Marie, 2003). Task trends in manufacturing also show a change from an individual’s linear problem-solving process to a team’s complex problem-solving process (Kelley, 2005). Therefore, this study investigated how the changes of shared mental models (Team-SMM and Task-SMM) affect team and individual performance in students manufacturing engineering teams.

According to Mohammed, Klimoski, & Rentsch (2000), the most common methods for measuring shared mental models have been pairwise ratings and Likert-scale questionnaires. They also suggested principal indicators of shared mental models are: (1) the similarity of team members’ knowledge structures of team and task components and (2) the degree of how closely one team member’s perceptions of teamwork and task work resemble other team members’ perceptions of teamwork and task work. In this study, we used the pairwise rating to measure the structure of the shared mental model, and used the Likert-scale questionnaires to measure the content of shared mental model. Specifically, the structure of shared mental models was captured through examining the relationships among the key components of the team and task. Also, the content of shared mental model was measured by asking participants how much they have a shared perception of their teamwork and task work using the Likert-scale questionnaires.

**Research Questions**

The main research question is ‘Is Team-SMM or Task-SMM the better predictor of team and individual performance?’ The research question is divided into the following two research questions. The specific theoretical and operational hypotheses are as follows.

1. Does Team-SMM or Task-SMM predict team performance? If so, how well do they predict team performance over time?

   Theoretical hypothesis: As Team-SMM or Task-SMM increases, team performance will increase.
• *Operational hypothesis 1.1:* As the similarity score on Team-SMM Structure or Task-SMM Structure increases, the team performance score will show a statistically significant increase.

• *Operational hypothesis 1.2:* As the average score of the perception ratings about Team-SMM Degree or Task-SMM Degree increases, the team performance score will show a statistically significant increase.

2. Does Team-SMM or Task-SMM predict *individual performance*? If so, how well do they predict *individual performance* over time?

### Methods

#### Participants

As the final numbers of participants, total sixty-seven undergraduate students were participated in this study. Their age range was from 20 to 25, and they were enrolled in an engineering class in a large public university located in the southeastern region of the United States. Students participated in the study voluntarily but extra credit points were given to them once they completed all required instruments.

To determine an appropriate sample size for this study, a power analysis was conducted based on Green’s (1991) formula that was used in Resick’s (2004) study. Green’s formula calculates a sample size needed to produce a reliable prediction equation considering the estimates of effect sizes. Green’s formula is \[ N \geq \left( \frac{8}{f^2} \right) + (m - 1) \], where \( f^2 \) = effect size estimate and \( m \) = number of predictors. Cohen (1988) suggested using estimates of an effect size of .02, .15, or .35 for small, medium and large effects respectively. In this study, each regression equation contains eight predictors including time dummy variables and interaction variables. Therefore, \( m = 8 \) and \( m - 1 = 7 \). The desired number of teams is as follows: 30 for large effects \([8 / .35] + (7)\), 60 for medium effects \([8 / .15] + (7)\), and 807 for small effects \([8 / .01] + (7)\). Using this approach, the desired number of teams is at least 30 \([8 / .35] + (3)\] with two participants per team; therefore, a total of 60 participants would be required. As a result, a total of 67 students were recorded as the final number of participants for the study and a sample size of 33 teams was chosen to provide a conservative approach to establishing statistical power. Each participant was randomly assigned to a team comprised of two students. The number of team members within each team was derived based on the number of roles (project manager & industrial designer) that are necessary for completing the team project.

#### Team Project

Team projects consisted of a complex ill-structured problem that had multiple possible solutions. According to Albers (2002), a complex problem requires problem solvers to make diverse decisions in a real world application. It entailed highly dynamic paths beyond a step-by-step process and called for various considerations of solutions. Thus, the result could be presented as several different viable solutions. In this study, the team project consisted of three phases. Overall, they needed to provide how they could improve the given manufactured product in terms of 1) materials, 2) manufacturing processes, 3) design for assembly and disassembly and 4) functionality and durability in their team project. In the first phase, each team was supposed to describe the given manufactured product in terms of properties and working principles. Also, teams broke down the product components and represented them in the form of an illustration. In the second phase, each team was supposed to describe each product component and identify the types of materials used to make each product component. Additionally, teams described the manufacturing processes used to
fabricate components including assembly procedures, automation, designs for assembly (DFA), and disassembly (DFD) considerations. In the last phase, based on durability and functionality tests, teams identified problems with the current design, and proposed new design(s) that served to improve the given product. An industrial engineering expert intentionally created three sub-tasks that have the same level of task difficulty for this study.

**Task Difficulty**

In addition to this, the task difficulty was also measured to confirm that the difficulty level of each task is the same. All participants were required to complete a task difficulty questionnaire that was used in Robinson’s (2001) study whenever they finished each of the three sub-tasks in their team project. The specific question items were presented in the following way, from left 0, to right 9:

1. I thought this task was easy/I thought this task was hard;
2. I felt relaxed doing this task/I felt frustrated doing this task;
3. I didn’t do well on this task/I did well on this task;
4. This task was not interesting/This task was interesting;
5. I don’t want to do more tasks like this/ I want to do more tasks like this.

The results showed that there was no statistically significant difference in the task difficulty level among the three sub-tasks. (Phase I; \( M = 5.21, SD = 1.14 \), Phase II; \( M = 5.39, SD = 0.98 \), Phase III; \( M = 5.22, SD = 0.94, t(66) = -1.41, p = 0.16 \) between Phase I and Phase II, \( t(66) = -0.12, p = 0.90 \) between Phase I and Phase III, and \( t(66) = 1.72, p = 0.09 \) between Phase II and Phase III).

**Data Collection**

As described before, the Team-SMM and Task-SMM data were collected in terms of their structure and degree of perception on task work and teamwork. For measuring Team-SMM structure and Task-SMM structure, student were supposed to do pairwise ratings on the key components of Team-SMM suggested by Mathieu, Heffner, Goodwin, Salas, and Cannon-Bowers (2000). They include: (a) Role/Responsibility, (b) Information Sources, (c) Interaction Patterns, (d) Communication Channels, (e) Role Interdependencies, (f) Information Flow, (g) Teammates’ Knowledge, (h) Teammates’ Skill, (i) Teammate’s Attitudes, (j) Teammate’s Preferences, and (k) Teammate’s Tendencies. Regarding key components on the Task-SMM, they were came up with the task analysis by two researcher who are familiar with the study purpose and questions, and one expert in the manufacturing engineering field. Participants judged the relatedness of team and task components whenever they finished their sub-task of their team project. The pairwise rating ranges from “-4” (negatively related, a high degree of one requires a low degree of the other) to “+4” (positively related, a high degree of one requires a high degree of the other). And Pathfinder program used to calculate the similarity scores.

On the other hand, Team-SMM Degree and Task-SMM Degree were measured by the 5-points Likert-scale Questionnaires ranging from 1 “strongly disagree” to 5 “strongly agree”. First, Team-SMM Degree questionnaire consists of measuring students’ perception on teammate knowledge and team interaction as shown in the Figure 1. Specific question items contain “My teammate has a general knowledge of specific team tasks”, “My teammate knows specific strategies for completing various tasks”, “My team communicates with other teammates while performing team tasks”, “My team can adopt flexibly any roles within my team”, etc. The questionnaire for measuring Task-SMM degree included students’ perception on task knowledge and team environment also presented in the Figure 1. The reliability (Cronbach’s alpha) of the Team-SMM Degree questionnaire on (1) Phase I, (2) Phase II, and (3) phase III were .982, .981, and .978, respectively. The reliability (Cronbach’s alpha) of the Task-SMM Degree questionnaire on (1) Phase I, (2) Phase II, and (3) Phase III were .980, .876 and .941, respectively. These Team-SMM Degree and Task-SMM Degree questionnaires also were administered after each three sub-task of the team project.
Regarding measuring individual performance and team performance, the individual performance was measured by a questionnaire that had five short-answer questions (e.g., “Which part do you think has the highest material cost?” , “What type of test would you perform to assess the durability of the product under service conditions?”, “Describe the step-by-step manufacturing processes”). Three different sets of questions were provided to the participants at the end of each of the three sub-tasks in their team project. The individual performance scores were also evaluated by two raters. The average of their scores was counted as the individual performance score. The inter-rater reliability was assessed by Kappa statistic. The results of the Kappa statistic showed the 0.74, 0.75 and 0.75 agreement of two raters in Phase I, Phase II and Phase III respectively. Because more than 0.60 was considered to be a substantial agreement (Landis & Koch, 1977), the individual performance scores were used for this study.

On the other hand, team performance was measured based on students’ team reports that were submitted at the end of each of the three sub-tasks in their team project. A modified version of the MET (Manufacturing Engineering Technology) criteria, validated in Nelson’s (1994) study, was used to evaluate the team reports. The average of team scores evaluated by two raters was counted as each team’s team performance score. Like the individual performance measure, inter-rater reliability was also assessed by Kappa statistic for each team performance measure. The obtained inter-rater reliabilities showed agreement of 0.71, 0.75 and 0.73\(^1\) in Phase I, Phase II and Phase III respectively. A Kappa value of more than 0.60 was considered to be a substantial agreement (Landis & Koch, 1977). Team performance and individual performance measures were conducted after participants completed each of the three sub-tasks of their team project.

**Data Analysis**

Random-effects GLS (Generalized Least Squares) regression or fixed-effects regression was selectively used to examine the study’s hypotheses. The results of this analysis showed how much of the variation in the dependent variables (i.e., team performance and individual performance) was explained by the change in independent variables (i.e., Team-SMM Structure, Team-SMM Degree, Task-SMM Structure and Task-SMM Degree) over time. The STATA 8.0 SE statistical package was used to carry out the random-effects GLS regression and fixed-effects regression.

**Results**

*Predicting Team Performance by Team-SMM or Task-SMM*

Regarding the relationship between SMMs Structure and Team performance, it was expected that the team performance score would show a statistically significant increase as the similarity score on Team-SMM Structure or Task-SMM Structure increases. This hypothesis was tested to examine the incremental predictability of the similarity score on Team-SMM Structure or Task-SMM Structure for team performance.

The overall model indicated a good fit with the data explaining about 58 % of the variation in team performance. As the results of Hausman Specification test indicate, the null hypothesis was not rejected so that the random-effects model was carried out to examine whether the similarity scores on Task-SMM Structure and Team-SMM Structure influenced team performance over time.

As the results of the analysis indicate, each coefficient of Task-SMM Structure and Team-SMM Structure did not significantly affect the increase of the average score in team performance. Also, they did not have any statistically significant impact on team performance in the specific time periods (i.e., from Time 1 to Time 2 and from Time 2 to Time 3). The

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\(^1\) Poor agreement = Less than 0.20, Fair agreement = 0.20 to 0.40, Moderate agreement = 0.40 to 0.60, Substantial agreement = 0.60 to 0.80, Almost perfect agreement = 0.80 to 1.00 (Landis & Koch, 1977)
following Table 1. shows the summary of the results.

Table 1. Results from Random-Effects GLS Regression of Task-SMM Structure and Team-SMM Structure on Team Performance

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient Estimate</th>
<th>Z-statistics</th>
<th>P&gt;abs. Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>18.486</td>
<td>16.03</td>
<td>0.000</td>
</tr>
<tr>
<td>Task-SMM Structure Score</td>
<td>-0.008</td>
<td>-0.29</td>
<td>0.769</td>
</tr>
<tr>
<td>Team-SMM Structure Score</td>
<td>-0.008</td>
<td>-0.30</td>
<td>0.766</td>
</tr>
<tr>
<td>T1</td>
<td>5.173</td>
<td>2.99</td>
<td>0.003</td>
</tr>
<tr>
<td>T2</td>
<td>3.067</td>
<td>2.10</td>
<td>0.036</td>
</tr>
<tr>
<td>T1 * Task-SMM Structure Score</td>
<td>-0.036</td>
<td>-0.97</td>
<td>0.332</td>
</tr>
<tr>
<td>T1 * Team-SMM Structure Score</td>
<td>0.007</td>
<td>0.14</td>
<td>0.890</td>
</tr>
<tr>
<td>T2 * Task-SMM Structure Score</td>
<td>0.005</td>
<td>0.14</td>
<td>0.888</td>
</tr>
<tr>
<td>T2 * Team-SMM Structure Score</td>
<td>0.011</td>
<td>0.30</td>
<td>0.767</td>
</tr>
</tbody>
</table>

R-square: within = 0.8155
between = 0.0034
overall = 0.5763

Number of Observation
99

Wald Test chi2(8)
266.09

Prob>chi-square
0.0000

Breusch-Pagan Lagrange Multiplier Test: Null Hypotheses: Var(u) =0
Calculated Chi-square(1) = 25.41
Prob > chi-square = 0.0000

Hausman Specification test: Null Hypothesis: No systematic difference in coefficients
Calculated Chi-square(8) = 2.59
Prob > chi-square = 0.9574

Notes: Model: Team Performance = \( \beta_0 + \beta_1 \) Task-SMM+ \( \beta_2 \) Team-SMM+ \( \beta_3 \) T1 + \( \beta_4 \) T2+ \( \beta_5 \) T1Task-SMM + \( \beta_6 \) T1Team-SMM +\( \beta_7 \) T2Task-SMM+\( \beta_8 \) T2Team-SMM, ***p \leq .001, **p \leq .01, *p \leq .05, T1: from Time 1 to Time 2, T2: from Time 2 to Time 3

In terms of the relationship between SMMs Degree and Team Performance, it was hypothesized that team performance scores would increase as the similarity scores of Team-SMM Degree or Task-SMM Degree increased. At first, the hypothesis was tested with the similarity scores of Task-SMM Degree and Team-SMM Degree. As the results of Hausman Specification test indicate, the null hypothesis was rejected so that the fixed-effects model was carried out to examine whether the similarity scores on Task-SMM Degree and Team-SMM Degree influenced team performance over time.

As shown in Table 3, the similarity score on Task-SMM Degree had a significant influence on team performance. As the similarity score on Task-SMM Degree increased by one point, team performance increased by approximately 4.266 points. In the specific time period from Time 1 to Time 2, Task-SMM Degree had a positive relationship with team performance while Team-SMM Degree had a negative relationship with team performance. Namely, a one-point increase in the similarity score on Task-SMM Degree led to a 5.613 point increase of
the average in team performance. However, around 2.954 points of the average in team performance decreased as the Team-SMM Degree increased by one point.

On the other hand, there were no statistically significant impacts of Task-SMM Degree and Team-SMM Degree on team performance from Time 2 to Time 3. The following Table 2. shows the summary of the results.

Table 2. Results from Fixed-Effects Regression of the Similarity Scores on Task-SMM Degree and Team-SMM Degree on Team Performance

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient Estimate</th>
<th>t</th>
<th>P&gt;abs. t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>7.159</td>
<td>1.59</td>
<td>0.118</td>
</tr>
<tr>
<td>Task-SMM Degree Score</td>
<td>4.266 ***</td>
<td>3.73</td>
<td>0.000</td>
</tr>
<tr>
<td>Team-SMM Degree Score</td>
<td>-1.250</td>
<td>-1.63</td>
<td>0.108</td>
</tr>
<tr>
<td>T1</td>
<td>-5.318</td>
<td>-1.24</td>
<td>0.219</td>
</tr>
<tr>
<td>T2</td>
<td>2.641</td>
<td>0.45</td>
<td>0.653</td>
</tr>
<tr>
<td>T1 * Task-SMM Degree Score</td>
<td>5.613 ***</td>
<td>4.58</td>
<td>0.000</td>
</tr>
<tr>
<td>T1 * Team-SMM Degree Score</td>
<td>-2.954 **</td>
<td>-2.96</td>
<td>0.004</td>
</tr>
<tr>
<td>T2 * Task-SMM Degree Score</td>
<td>-1.335</td>
<td>-0.99</td>
<td>0.328</td>
</tr>
<tr>
<td>T2 * Team-SMM Degree Score</td>
<td>0.931</td>
<td>1.04</td>
<td>0.303</td>
</tr>
</tbody>
</table>

R-square: Within = 0.8694
between = 0.7264
Overall = 0.7741

Number of Observation 99
F(8,58) 48.26
Prob>F 0.0000

Breusch-Pagan Lagrange Multiplier Test: Null Hypotheses: Var(u) = 0
Calculated Chi-square(1) = 2.51
Prob > chi-square = 0.1130

Hausman Specification test: Null Hypothesis: No systematic difference in coefficients
Calculated Chi-square(8) = 16.08
Prob > chi-square = 0.0412

Notes: Model: Team Performance = \( \beta_0 + \beta_1 \text{Task-SMM} + \beta_2 \text{Team-SMM} + \beta_3 T1 + \beta_4 T2 + \beta_5 T1\text{Task-SMM} + \beta_6 \text{T1Team-SMM} + \beta_7 T2\text{Task-SMM} + \beta_8 T2\text{Team-SMM}, *** p \leq .001, ** p \leq .01, * p \leq .05 \), T1: from Time 1 to Time 2, T2: from Time 2 to Time 3

Predicting Individual Performance by Team-SMM or Task-SMM

Regarding the relationship between SMMs Structure and individual Performance, it was hypothesized that the individual performance score will show a statistically significant increase as the similarity scores on Team-SMM Structure or Task-SMM Structure increase. Since the null hypothesis of Hausman Specification test was not rejected, the random-effects model was used to examine how the increases of the similarity scores on Task-SMM Structure and Team-SMM Structure affect the improvement of individual performance.
Overall, the similarity scores on Task-SMM Structure and Team-SMM Structure did not have any statistically significant impact on individual performance. However, the similarity score on Team-SMM structure from Time 2 to Time 3 had a statistically significant positive impact on individual performance at the 5% significance level. Specifically, an increase of one point in the similarity score on Team-SMM Structure led to the increase of the average score in individual performance by 0.483 points holding all other independent variables constant. The following Table 3 shows the results of the analysis.

Table 3. Results from Random-Effects GLS Regression of Task-SMM Structure and Team-SMM Structure on Individual Performance

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient Estimate</th>
<th>Z-statistics</th>
<th>P&gt;abs. Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>57.567</td>
<td>10.31</td>
<td>0.000</td>
</tr>
<tr>
<td>Task-SMM Structure Score</td>
<td>-0.002</td>
<td>-0.01</td>
<td>0.991</td>
</tr>
<tr>
<td>Team-SMM Structure Score</td>
<td>-0.177</td>
<td>-1.25</td>
<td>0.210</td>
</tr>
<tr>
<td>T1</td>
<td>-0.249</td>
<td>-0.03</td>
<td>0.978</td>
</tr>
<tr>
<td>T2</td>
<td>-15.339</td>
<td>-1.94</td>
<td>0.053</td>
</tr>
<tr>
<td>T1 * Task-SMM Structure Score</td>
<td>0.084</td>
<td>0.43</td>
<td>0.669</td>
</tr>
<tr>
<td>T1 * Team-SMM Structure Score</td>
<td>0.067</td>
<td>0.25</td>
<td>0.804</td>
</tr>
<tr>
<td>T2 * Task-SMM Structure Score</td>
<td>0.148</td>
<td>0.77</td>
<td>0.440</td>
</tr>
<tr>
<td>T2 * Team-SMM Structure Score</td>
<td>0.483 **</td>
<td>2.58</td>
<td>0.010</td>
</tr>
</tbody>
</table>

R-square: within = 0.1950  
between = 0.0013  
overall = 0.1054

Number of Observation: 201
Wald Test chi2(8): 29.38
Prob>chi-square: 0.0003

Breusch-Pagan Lagrange Multiplier Test: Null Hypotheses: Var(u) = 0  
Calculated Chi-square(1) = 9.36  
Prob > chi-square = 0.0022

Hausman Specification test: Null Hypothesis: No systematic difference in coefficients  
Calculated Chi-square(8) = 11.94  
Prob > chi-square = 0.1539

Notes: Model: Individual Performance = \( \beta_0 + \beta_1 \text{Task-SMM} + \beta_2 \text{Team-SMM} + \beta_3 T1 + \beta_4 T2 + \beta_5 T1T\text{Task-SMM} + \beta_6 T1\text{Team-SMM} + \beta_7 T2\text{Task-SMM} + \beta_8 T2\text{Team-SMM} \), ***p \leq .001, **p \leq .01, *p \leq .05, T1: from Time 1 to Time 2, T2: from Time 2 to Time 3

In terms of the relationship between SMMs Degree and individual performance, it was hypothesized that individual performance score will show a statistically significant increase as the average score of Team-SMM Degree or Task-SMM Degree increase. The results of the Breusch-Pagan Lagrange Multiplier test and the Hausman Specification test justified the choice of random-effects GLS regression. The regression was used to see how much the increase of the similarity scores of Task-SMM Degree and Team-SMM Degree influence the increase of individual performance.
Overall, Team-SMM Degree had significantly positive impacts on the improvement of individual performance at the 5% significance level. The individual performance score increased by 8.514 points as the similarity scores on Team-SMM Degree increased by one point. Also, an increase of one point in Team-SMM Degree resulted in an increase in the average of individual performance by 10.954 points at the time period from Time 1 to Time 2. The following Table 4. shows the summary of the results.

Table 4. Results from Random-Effects GLS Regression of the Similarity Scores on Task-SMM Degree and Team-SMM Degree on Individual Performance

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient Estimate</th>
<th>Z-statistics</th>
<th>P&gt;abs. Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>34.649</td>
<td>1.55</td>
<td>0.122</td>
</tr>
<tr>
<td>Task-SMM Degree Score</td>
<td>-4.414</td>
<td>-0.73</td>
<td>0.465</td>
</tr>
<tr>
<td>Team-SMM Degree Score</td>
<td>8.514*</td>
<td>2.18</td>
<td>0.030</td>
</tr>
<tr>
<td>T1</td>
<td>-11.101</td>
<td>-0.46</td>
<td>0.643</td>
</tr>
<tr>
<td>T2</td>
<td>-18.833</td>
<td>-0.56</td>
<td>0.578</td>
</tr>
<tr>
<td>T1 * Task-SMM Degree Score</td>
<td>-7.369</td>
<td>-1.14</td>
<td>0.255</td>
</tr>
<tr>
<td>T1 * Team-SMM Degree Score</td>
<td>10.954 *</td>
<td>2.13</td>
<td>0.033</td>
</tr>
<tr>
<td>T2 * Task-SMM Degree Score</td>
<td>7.811</td>
<td>1.03</td>
<td>0.305</td>
</tr>
<tr>
<td>T2 * Team-SMM Degree Score</td>
<td>-1.934</td>
<td>-0.36</td>
<td>0.718</td>
</tr>
</tbody>
</table>

R-square: within = 0.1749, between = 0.0440, overall = 0.1187

Number of Observation
201

Wald Test chi2(11) 30.22
Prob>chi-square 0.0002

Breusch-Pagan Lagrange Multiplier Test:
Null Hypotheses: Var(u) = 0
Calculated Chi-square(1) = 7.29
Prob > chi-square = 0.0069

Hausman Specification test:
Null Hypothesis: No systematic difference in coefficients
Calculated Chi-square (8) = 3.11
Prob > chi-square = 0.9275

Notes: Model: Individual Performance = $\beta_0 + \beta_1$Task-SMM + $\beta_2$Team-SMM + $\beta_3$T1 + $\beta_4$T2 + $\beta_5$T1Task-SMM + $\beta_6$T1Team-SMM + $\beta_7$T2Task-SMM + $\beta_8$T2Team-SMM, ***p ≤ .001, **p ≤ .01, *p ≤ .05, T1: from Time 1 to Time 2, T2: from Time 2 to Time 3

The summary of the results of this study was described in Table 5. Overall team performance was not affected by Task-SMM Structure or Team-SMM Structure. However, team performance increased as the similarity score on Task-SMM Degree increased, which means team members' highly shared perceptions on task knowledge and team environment improved their team performance. One interesting result is that team performance decreased as the similarity score on Team-SMM Degree increased from Time 1 to Time 2. On the other hand, overall, individual performance increased as the similarity score on Team-SMM Degree increased over time. Individual performance increased as the similarity score on Team-SMM
Structure increased from Time 2 to Time 3. Also, the increases of the similarity scores on Team-SMM Degree and Team-SMM Structure led to the increase of individual performance from Time 1 to Time 2 and from Time 2 to Time 3 respectively.

Table 5. Summary of the relationships between SMM and Team/Individual Performance

<table>
<thead>
<tr>
<th>SMM</th>
<th>Task-SMM</th>
<th>Team-SMM</th>
<th>T1 * Task-SMM</th>
<th>T1 * Team-SMM</th>
<th>T2 * Task-SMM</th>
<th>T2 * Team-SMM</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP&lt;sup&gt;a&lt;/sup&gt; Structure</td>
<td>φ</td>
<td>φ</td>
<td>φ</td>
<td>φ</td>
<td>φ</td>
<td>φ</td>
</tr>
<tr>
<td>Degree</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>φ</td>
<td>φ</td>
</tr>
<tr>
<td>IP&lt;sup&gt;b&lt;/sup&gt; Structure</td>
<td>φ</td>
<td>+</td>
<td>φ</td>
<td>φ</td>
<td>φ</td>
<td>+</td>
</tr>
<tr>
<td>Degree</td>
<td>φ</td>
<td>+</td>
<td>φ</td>
<td>+</td>
<td>φ</td>
<td>φ</td>
</tr>
</tbody>
</table>

Notes: a: Team Performance, b: Individual Performance, +: statistically significant increase, -: statistically significant decrease, φ: no statistically significant results, T1: From Time 1 to Time 2, T2: From Time 2 to Time 3

Conclusion

This study focused on explicating the influence of Team-SMM and Task-SMM on team and individual performance. In previous studies, some researchers found significant relationships between Team-SMM and team performance but not between Task-SMM and team performance (e.g., Leversque, Wilson and Wholey, 2001; Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000). Others found that Team-SMM is less predictive of performance than Task-SMM (e.g., Mathieu, Heffner, Goodwin, Cannon-Bowers, & Salas, 2005). Moreover, Lim and Klein (2006) found that both Team-SMM and Task-SMM were significantly positively related to team performance. In this study, the relationships between SMMs and team performance and between SMMs and individual performance and how these relationships change over time were statistically examined by the random-effects GLS regression or fixed-effects regression analyses.

With regard to the relationships between SMMs Structure and team/individual performance, individual performance was affected by Team-SMM Structure while team performance was not influenced by either Team-SMM Structure or Task-SMM Structure. Unlike the study of Mathieu et al. (2000) who found that Task-SMM did not correlate significantly with team performance but that Team-SMM was closely related to team performance, team performance in the present study was not affected by either Task-SMM Structure or Team-SMM Structure over time. On the other hand, individual performance was not affected by either Task-SMM Structure or Team-SMM Structure at the specific time period from Time 1 to Time 2. However, from Time 2 to Time 3, individual performance increased as the similarity score on Team-SMM Structure increased. This implies that a high sharedness of Team-SMM Structure at the end of the project plays an important role in their individual performances.

Moreover, the results showed interesting relationships between SMMs Degree and team/individual performance. Overall, a highly-shared perception on Task-SMM (Task-SMM Degree) is a dominant factor to increase team performance while a highly-shared perception on Team-SMM (Team-SMM Degree) is an important factor to improve individual performance over time. There are some possible reasons why the Task-SMM Degree and Team-SMM Degree showed different relationships with team performance. A possible reason may be related to the measurement of team performance. In this study, team performance was...
measured by their team projects that focused on task-related knowledge. If the team performance measurement included team-related ability or knowledge, the results might be different. Second, the results suggest that Task-SMM is a more predictive factor of team performance than Team-SMM in performing a team project that requires a relatively short period of time (Lim & Klein, 2006). Due to the limited time period to accomplish the team project, it might be difficult for team members to fully share Team-SMM that consists of teammate knowledge and team interaction. The process of sharing Team-SMM may be rather detrimental in performing their projects.

At the specific time period from Time 1 to Time 2, team performance increased as the similarity score on Task-SMM Degree increased while it decreased as the similarity scores of Team-SMM Degree increased. Namely, team performance had a positive relationship with the similarity score on Task-SMM; however, it had a negative relationship with the similarity scores of Team-SMM. On the other hand, individual performance had a positive relationship with Team-SMM over time and the positive relationship was specifically important at the time period from Time 1 to Time 2. This implies that highly-shared perceptions on teammate knowledge and team interactions are important to enhance individual performance at the beginning of the team project. The possible reason why Team-SMM is positively associated with individual performance is that individuals belonged to their team and they were involved in team cognitive processes. Even though individual performance was measured by individual team members, their perceptions may be affected by the team project on which they worked. This result also supports that individual team member’s thinking process cannot be separated from the team thinking process as long as the individual belongs to a team (Cooke et al., 2004).

Overall, the findings of this study provided evidence that Team-SMM and Task-SMM had unique influences on team and individual performance. Moreover, the unique influences varied depending on task and team demands in the specific time period of a team project.

Implications and Suggestions

This study provides several important theoretical and practical contributions to the area of shared mental models and performance. First, this study employed a panel data analysis because the data was collected over time and with the same individuals in this field of shared mental model studies. Specifically, a random-effects GLS regression and fixed-effects regression were selectively used based on the results of the Hausman Specification test and the Breusch-Pagan Lagrange Multiplier test. Due to the consideration of panel data in nature, a random-effects GLS regression and fixed-effects regression was more appropriate than conducting multiple regressions per each time point. Through the random-effects GLS regression or fixed-effects regression analysis, it was possible to identify the time point of when Team-SMM or Task-SMM mainly influenced team and individual performance during a complex team project.

Second, this study fulfilled the need of the shared mental model studies in the field of a manufacturing engineering education. According to Langan-Fox, Anglim, and Wilson (2004), there have been no substantial efforts to study teams of students in educational settings. In particular, manufacturing engineering education deals with many complex problems and requires teams of students to work together to find solutions to the complex problems. In order to understand how to improve team performance as well as individual performance in the manufacturing engineering education field, it is necessary to conduct studies to uncover the mechanism of shared mental models and its effect on performance. With regard to this, this study contributes to these needs.

Third, this study also investigated the relationship between shared mental models and individual performance. Many researchers tend to focus on the shared mental model and its effect on team performance (Griepentrog & Fleming, 2003; Kraiger & Wenzel, 1997; Rouse, Cannon-Bowers, & Salas, 1992). There is a lack of studies on the relationships between shared mental models and individual performance. However, shared mental models can...
affect individual performance because shared mental models and individual mental models are closely interwoven (Cooke et al., 2004). Therefore, this study contributed to the investigation and revealed that shared mental models positively affect individual performance.

Based on the results of this study, three research topics can be suggested as the future research. First, they should focus on building a strong foundation of shared mental model research fields through theoretical and empirical studies on factors, measurement techniques, and the relationship with performance. Second, research on developing a computer simulation program or any supporting tool which can automatically display the change of shared mental models and its relationship with team and individual performance should be conducted. This will help students to diagnose their process in the team project and adjust their teamwork and task work appropriately. Third, the unveiled underlying mechanism of the dynamic relationship between shared mental models and performance should be considered in designing online and offline instructions in complex team-based learning. The instructions could support team members to accomplish their team project effectively and efficiently. Specifically, they will be able to help team members to understand what is going on with the task and to easily anticipate what may happen next as well as which actions they need to take to improve team and individual performance.

REFERENCES