The influence of a problem solving training on shared mental models of spatial planners

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Abstract

Shared mental models of spatial planners

A methodology for spatial planners was developed to support very complex cooperative problem solving processes in this field. Learning and training this methodology should improve shared mental models of best practise and shared awareness of work processes. This should lead to more efficient cooperation and better results for planning teams. We compared trained teams of students with novices in an experimental study. The activities of the planning teams, interview protocols, and the work results were observed and analysed. The methodological training improved the degree of matching between mental models within the teams and the work results. New theoretical assumptions about the role of shared mental models for complex work processes have been developed.

Keywords

Shared mental model – complex problem solving – spatial planning

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1 Introduction

Problem solving processes in spatial planning are very often complex and deficient. Spatial planners must take into account a large number of heterogeneous aspects (social, ecological economical, political, and administrative). The results of planning cannot be seen immediately after the decisions and activities have been concluded. Often, positive and negative outcomes as well as side effects cannot be seen until much later. Hence, spatial planners get no immediate and only poor feedback on the consequences of their activities (von der Weth, 2002). Many stakeholders with different interests are involved in spatial planning projects. Therefore, the actors have to find compromises without firm knowledge about the outcome of possible actions. Spatial planning is not just a design process, but also a search for consensus between the decision makers involved and the people concerned. Because all these people often have a very heterogeneous background, a lot of discrepancies can be caused by different planning approaches (Schönwandt & Voigt, 2005). These are paradigmatic assumptions about the background and the basic mechanisms of the problem situation. The planning approaches have a great influence on the course of discussions, decisions, and activities. A planning methodology was developed for coping with complex tasks in the field of spatial planning in a better way. The content of a course based on this methodology consisted of a curriculum of 20 units with topics like participation of stakeholders, forecasting methods, assessment of measures and projects. According to this methodology, at least six core activities have to be performed:

1. Planners must find problem definitions which can be communicated to most stakeholders in the planning process. These problem definitions

should be as concrete as possible („Discussing problems").

2. To enlarge the search space for solutions, the problems have to be „shifted". The idea is to find new formulations, which allow more solutions to be found which are convenient and useful for most stakeholders („Problem shifting").
3. Because spatial planning is very complex, the causes of the problem should be analysed very carefully („Discussing causes").
4. This analysis should allow a stringent derivation of measures from these causes. The resulting measures should be designed to solve the problem effectively in the long run („Generating measures").
5. The definition of keywords should generate common understanding about the problem. The problem space, the goals, and the number of possible solutions change according to these definitions („Defining concepts").
6. Every planner uses a so called „planning approach". Problems can be solved by different approaches. Users of the planning methodology should learn to explore and to switch between different approaches. This helps to criticise their own approach, to broaden their own horizon, and to find more possible solutions and compromises which are convenient for all groups involved (Schönwandt & Voigt, 2005) („Discussing planning approaches").

These core activities of the planning methodology are called „key six"; for more information see Hemberger and colleagues (2008a). The spatial planning methodology described above does not prescribe a fixed sequence for these activities. Usually, they are conducted several times in an iterative loop.

This methodology improved the performance of spatial planning teams who took part in a 10 days training course (von der Weth et al., 2008). The next step was to find out in which way the cooperation in spatial planner teams was influenced by the training and, on the other hand, which psychological processes at team level influenced the process and the result.

According to empirical research in cognitive psychology, an important reason for a good team performance is the degree of matching of cognitive representations in teams. Klimoski and Mohammed (1994) describe this as „team mental models", and Cannon-Bowers, Salas, and Converse (1993) discuss „shared mental models". According to these theories, shared mental models allow a correct anticipation of future developments of a situation, and facilitate the team coordination (Cannon-Bowers, Salas, & Converse, 1993; Klimoski & Mohammed, 1994). The authors have different ideas about the content of these representations. According to Klimoski and Mohammed, the declarative part of team mental models consists of task aspects (e.g., goal definitions, success factors, important stimuli in the environment) and team aspects (e.g., role allocation, responsibilities, attitudes). The concept of „shared mental models" is more differentiated (Cooke, Salas, Cannon-Bowers, & Stout, 2000). It is related to attributes of the tasks and distinguishes four knowledge domains which can be more or less concordant within a team. The so called *„equipment model"* is about infrastructure and equipment (e.g., tools, machines, and their function). The possible actions and their outcomes are limited by these factors. Strategies, tactics, and heuristics for problem solving and knowledge of the demands are called the *„task model"*. The *„team interaction model"* is related to communication channels and patterns, responsibilities, and role allocation, whereas the *„team model"* is about abilities, skills, and other attributes of the team members. Most contents of the spatial planning methodology are related to the task model, which is also according to Cannon-Bowers and colleagues (1993) an important aspect for successful acting. First studies about the correlation between shared mental models and performance were done with professional teams under time pressure such as war plane crews (Rouse, Cannon-Bowers, & Salas, 1992). Later, the shared mental model approach was expanded to tasks in less dynamic environments like traditional organisations (e.g., Levine & Moreland, 1999). According to Badke-Schaub (2002), the development of shared mental models is an important step towards better cooperation and performance in mechanical design. These models should be flexible to enable design teams to implement flexible project management strategies.

The training course examined in this study should help develop a higher degree of matching of the task models within teams. According to different models about developing expertise (e.g., Anderson, 2005; Schön, 1983; Hacker, 1992), learning action strategies start with declarative knowledge about procedures, heuristics, and strategies. In professional contexts such knowledge is taught in schools, universities, or vocational training. With more and more experience, this knowledge will be adjusted to the requirements of the specific actor (e.g., tuning; c.f. Anderson, 2005). This is not a process of mere conditioning or model learning, but a process in which acting and reflection are interacting in a highly differentiated way (Schön, 1983). According to Hacker (1992), experts develop a more and more differentiated task model. Information in this model enables the expert to take into account all „w-questions" in his/her activities (who? when? where? what? why?). A methodological teaching course which gives (a) a theoretical foundation and description of the process, (b) the chance to develop shared experience in applying this methodology, and (c) opportunities for teams to reflect these activities should help to develop a common approach towards how to solve complex problems. If this works, the same team should improve its cooperation in other complex tasks as well. Trained teams should have more concordant task models as well as improved cooperation and better results.

2 Method and sample

A control group design was chosen for this study (Figure 1). The participants were students of the Faculty of Architecture and Urban Planning at the University of Stuttgart. They were rewarded with credit points. The best team in the experiment got the chance to participate in an excursion to a high-tech civil engineering project (tunnelling in St. Gotthard, Switzerland). First of all, the abilities and qualifications of the 58 participants of the study were observed (a questionnaire about work experience and study results, questionnaire on planning styles [Hacker, 1994]). There were no differences between the experimental group and the control group.

The experimental group was then given provided a training course in planning methodology. The control group had to work on example tasks of the course, but without learning the rules of the methodology. In this way the authors ensured that the effects of the training derived from the methodology rather than from learning by doing. Moreover a process of team building was possible in both groups. Measures of team cohesion were very high in both groups and without significant differences. After that, the participants had to work on a realistic spatial planning task: to make proposals of how to solve a complex traffic problem.

The instructions for the first task started as follows: „The B27 motorway is one of the busiest roads in Stuttgart where there are often traffic jams. Yesterday, exponents of different interest groups had a meeting with the mayor of the city for a round table discussion. Political parties, business representatives, residents, environmentalists, and spatial planners took part. After long discussions about expansion of the road network and the resulting particulate matter emission, the discussion was adjourned ... "

The result should be a conceptual study of about 12 pages. The participants worked in teams of three students. They had to be ready in three days. Before and after the course the experimental variables were observed. The students of the control group took part in the training course several weeks later, and after that both groups again worked on a second complex spatial planning task concerning housing shortage in the city and region of Stuttgart (Germany). Before and after that second task the experimental variables were observed again.

3 Stimuli and Design

The *treatment* of this experiment was a ten days course in the planning methodology described above. The course consisted of teaching elements and training sequences. For more information see Hemberger and colleagues (2008a). The registration of *knowledge* was based on a questionnaire with „teaching back" instruction (Strohschneider, 1990). The subjects had to describe the best practise strategy for solving this planning problem. They had to explain the problem solving strategy adequately. For the answers to these open questions a so-called *„matching index"* was computed in the following way: the answers in the open question-

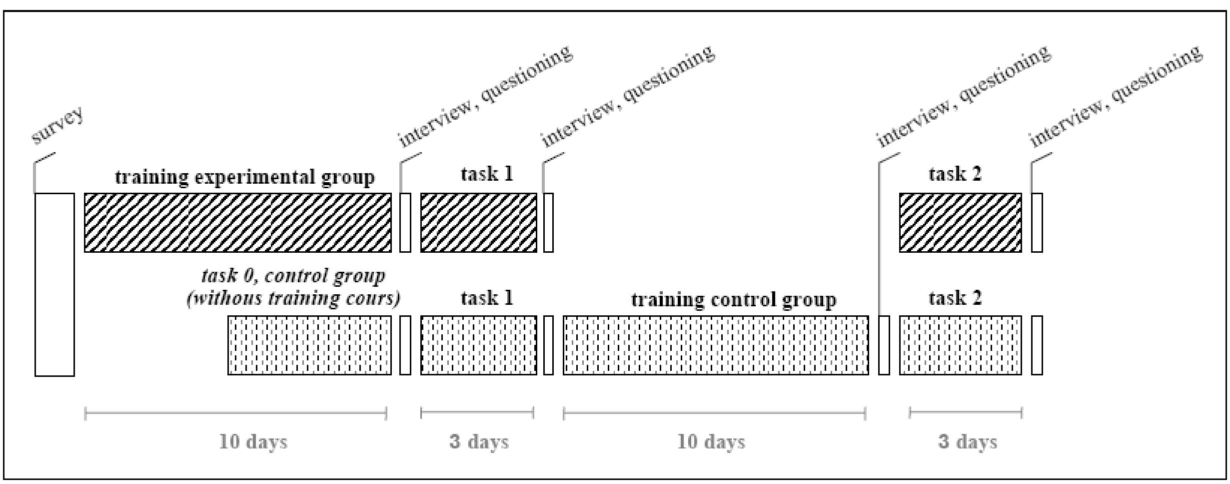

Figure 1: Experimental design

naire were compared to a list of 21 possible activities (Table 1).

Table 1: Methodological steps analysed in this study

1	**Discussing planning approaches**
2	Discussing problems and aims
2.1	Discussing initial state of planning
2.2	**Discussing problems**
2.3	Discussing advantages of problems
2.4	Discussing aims
2.5	**Problem shifting**
2.6	**Defining concepts (terms)**
2.7	Examining propositions
3	Compiling forecasts
4	**Discussing causes**
5	Discussing measures
5.1	**Generating measures**
5.2	Discussing constraints
5.3	Examining and assessing measures
5.4	Proposing measures for implementation
6	Discussing general frameworks
6.1	Discussing political arena and political agenda
6.2	Proposing participation of stakeholders
7	Gathering information
8	Organizing working process

Note: The most important steps (key six) are marked **in bold.**

19 of them were related to methodological steps and six of these were central methodological categories (key six). Additionally, we defined two more activities not defined in methodology, „gathering information“ and „organisation of work processes“. The rest was categorised as „behaviour not related to methodology“ and „behaviour not related to the task“. From these data we derived a methodological profile of each subject. Finally, we compared the degree of matching of this profile to the key six categories. The matching index increased by 1 point when two team members had a match for a methodological category and by 2 points when this category appeared in all profiles of the same team.

The quality of the course was assessed by a standardised questionnaire for teaching evaluation after the courses. It was about the satisfaction of the participants with the content, teachers’ performance, and the organisational and technical prerequisites for their work.

To analyse the *planning activities*, the work process of all groups was continually observed by specially trained monitors through all three days. Every five minutes the predominant activity of this interval was recorded in a log sheet. The sum of 21 categories for activities which could be assigned to certain methodological steps was summarised as „methodological activity“. Six of these categories can be described as core activities of methodological planning; the sums were the key six activities. As mentioned above, these activities are unique and typical of the methodological approach, which underlies the training course evaluated in this study. The remaining four categories were summarised as „non-methodological categories“.

To compare the observed activities with the cognitive representation of their own activities, the subjects had to *describe their own problem solving process*: after finishing the work on the planning tasks, they had to answer an open question („How did you proceed in your work process?“) and fill in a questionnaire about the intensity and importance of all 21 methodological activities. The open description was analysed in the same way as the question concerning best practise, calculating a „completeness index“. A higher index indicates a more methodological reflection of the problem solving process. The additional questions should help to assess the general importance of the methodology for good results and the importance of specific steps of the methodological process.

After these open and closed questionnaires a discussion within the teams took place. A description of the planning process and an analysis of their own strengths and weaknesses in the work processes were asked for. The questions were based on an expert interview by Hacker (1992). The question of whether a group was able to discuss its own work objectively after methodological training was analysed. This is indicated by a lower level of blaming each other in the case of failure and generally a lower portion of group dynamic topics in the discussion, compared to the analysis of the problem solving process and contents related to spatial planning.

The *quality of the resulting conceptual studies* was assessed by an expert rating using 77 criteria. It was conducted independently by 3 experts from the Institute for the Foundations of Planning. These experts did not know whether the studies belonged to the experimental group teams or to the control group. There was a 5-step-ranking for each criterion; thus it was possible to make three rankings for the quality of the studies: one for the first task, one for the second task, and also one for both tasks together. Moreover, we analysed the number of solution proposals which were made in the respective conceptual study. A broader variability of solutions improves the quality of a conceptual study because it generates a greater selection of possible other solutions which could be useful in the case of conflicts or changes in the demands of the task.

Control variables consisted of a questionnaire concerning the individual planning style (Hacker, 1994) in the beginning, and several scales from a ques-

Table 2: Overview of research methods used (research plan)

	Start	After first training / before first task	During first task	After first task / before second training	After second training / before second task	During second task	After second task
Course evaluation		x			x		
Planning style	x						
Team work questionnaire				x			x
Knowledge	x	x		x	x		x
Behaviour recording			x			x	
Self reflection				x			x
Team reflection				x			x

tionnaire on team qualitiy (TeamPuls by Wiedemann et al., 2001). Two processes were observed by video recordings of all activities. This allows the performance of detailed single case analyses.

The following table 2 shows when these methods were applied during the course of the study.

4 Research questions and hypotheses

The effects of the training course were analysed for individuals and teams. On an individual level, strong effects of the teaching course could be shown (von der Weth et al., 2008): the usefulness of the course was rated highly. After the training course the individual cognitive representations were based more strictly on methodological concepts. This influenced the representation of the individual activities and the ideas about best practise. The effects of this course on individual behaviour and an improvement of results could be found. According to our assumptions, these findings should be connected with the development of shared mental task models.

Higher degree of matching of mental models: we began with the assumption that the new planning methodology includes important elements of a task model (heuristic rules, strategies, plans). Therefore, the teaching course should improve the shared mental models of the teams. There should be a better consensus about the best way to perform in the planning tasks. Moreover, we believed that there is a higher degree of matching of the cognitive representation of the own problem solving process. Both variables were measured by a specific matching index. There should be a difference between the experimental and the control group after the first task and a significant improvement in the control group between the first and second tasks.

Correlation between matching indices and behaviour measures (strategy): then we tested the assumption that shared mental models based on the teaching course are correlated to a behaviour more organised according to methodological principles. We analysed the correlation between the two matching indices described above (best practise, individual strategy) on the one hand and the amount of time used for key six activities on the other hand. According to our hypotheses, such correlations between mental models and performed strategies do exist.

Correlation between degree of matching and results: finally the connection between the matching indices and the outcome of the planning process was tested. Correlations should exist between the matching indices (best practise, own strategy) and the ranking of the results.

5 Results

Improved shared mental models: we tested the effects of the training course by a multivariate analysis of variance (MANOVA). First we analysed the matching of the best practise models (Figure 2, left). It could be shown that there is a significant difference between the two tasks ($F(1,0) = 11.21$, $p < .01$, partial $\eta^2 = .38$). There is also a significant interaction effect ($F(1,0) = 23.40$, $p < .01$, partial $\eta^2 = .56$). Testing the effects on the representation of the teams' problem solving process again, an effect could be found. Although there was no significant difference between the two tasks ($F(1,0) = 2.08$, n.s.), an interaction effect could be found ($F(1,0) = 7.92$, $p < .01$, partial $\eta^2 = .30$, Figure 2, right). The teaching course influenced the shared awareness of the individual activities significantly.

Correlation between matching indices and behaviour measures (strategy): it could be shown that there is a strong correlation between the matching indices and the general amount of methodologically oriented activities. The matching indices for best practise (Spearman rank correlation coefficient, $r_s = .383$, $p < .01$) and for individual problem strategy ($r_s = .419$, $p < .01$) both correlated to this variable. Analysing the shared mental models on a single item level, we found the following correlations between the degree of matching best practise models and key six activities (Table 3). According to the detailed results, this index was connected with the amount of time needed to discuss about measures and their causes.

Correlation between matching indices and results: it could be shown that there is a strong correlation between the matching indices and the rankings of the results. Both the matching indices for best practise

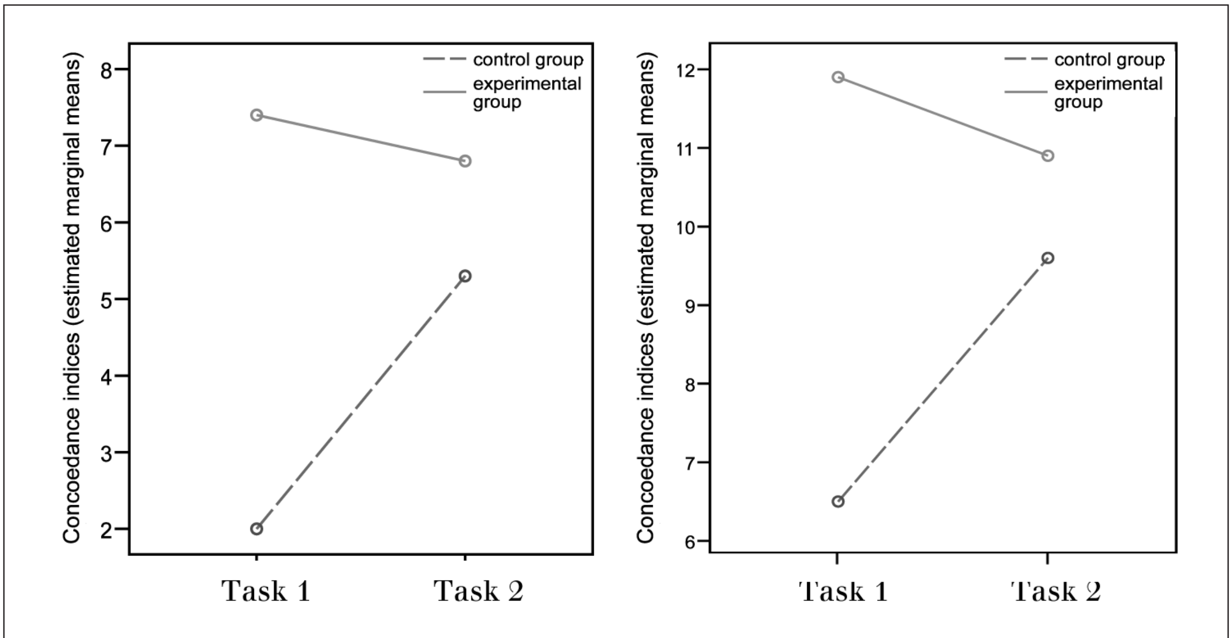

Figure 2: Matching indices of best practise (left) and of the representation of the individual activities (right).

Table 3: Correlations between single items of shared mental models about best practise and key six activities

Matching index for best practise aspects (Single Items)	Key six activities (Behaviour)
Discussing planning approaches	$r_s = .148$, n.s.
Discussing problems	$r_s = .292$, n.s.
Problem shifting	$r_s = .246$, n.s.
Defining concepts (terms)	$r_s = .170$, n.s.
Discussing causes	$r_s = .327$, $p < .05$
Generating measures	$r_s = .533$, $p < .01$

Table 4: Correlations between single items of shared mental models about best practise and quality of conceptual studies

Matching index for best practise aspects (Single items)	Quality of conceptual studies
Discussing planning approaches	$r_s = .249$, n.s.
Discussing problems	$r_s = .513$, $p < .01$
Problem shifting	$r_s = .013$, n.s.
Defining concepts (terms)	$r_s = .169$, n.s.
Discussing causes	$r_s = .516$, $p < .01$
Generating measures	$r_s = .450$, $p < .01$

($r_s = .477$, $p < .01$) and for individual problem strategy ($r_s = .646$, $p < .01$) correlated to this variable. Analysing shared mental models on a single item level, we found the following correlations between results and degree of matching about best practise (Table 4).

6 Discussion

The results show that the methodological course influenced the shared mental models of team members, the cooperative work process, and its results in a positive way. The methodological knowledge learned in this context was an important part of the task model of the participants. The training course changed the perceived competence for complex spatial planning tasks. The subjects found the methodological strategies useful. After training the methodology and working on a complex planning task, they developed a higher degree of matching of the mental models within the teams. The ideas about what makes a good problem solving strategy and the perception of their own work process became more similar. Apparently, this depended on certain behaviour patterns induced by methodological training. Subjects spending more time on discussion of the causal network of the problem and on the reasons for proposed measures developed shared mental models in a better way. The improved quality of results of teams with a higher degree of matching indicated that shared mental models, improved by methodological training, led to more efficient cooperation within the teams.

We assume that methodological training generates a basic structure to assess the quality of possible activities in the work process (shared mental models about best practise) and harmonises the perception of opportunities and threats (shared perception of the individual work process). The common methodological basic structure regulates the process of problem solving and makes it more effective and successful. Additionally, plausible methodological training and better cooperation in following work processes leads to more subjective control in that work process. According to empirical results (Dörner, 1996; Jansson & Smith, 1989), this lowers the probability of making serious mistakes in complex problem solving.

Whether the improvement in cooperation works in work constellations outside the university has to be analysed in further studies. There are additional aspects which have to be included in our research, e.g., in which way do conflicts and power struggles coming from diverging interests and a more interdisciplinary context influence the planning process and the results? A field study is planned to improve our knowledge about shared mental models in complex work processes in the domain of spatial planning.

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