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Complex Problem Solving after Unstructured Discussion: Effects of Information Distribution and Experience

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This study analyzes the effect of information overlap in groups discussing a complex problem on individual post-discussion complex problem solving (CPS). We hypothesize that information distribution among group members has an inverse u-shaped effect on individual post-discussion performance, favoring groups with a medium informational heterogeneity. As CPS is presumably correlated with experience, we also assume that exposure to the problem before the actual task leads to higher performance than less or no exposure. Experimental results support the first hypothesis: A medium overlap of instructional text paragraphs in dyads led to higher performance in a computer-simulated complex problem than complete or no overlap. The second hypothesis is not supported. Limitations of the study and practical implications are discussed.

KEYWORDS complex problem solving, knowledge exchange, team learning

In today's dynamic information-based work environments, many important tasks such as ongoing managerial decision making and designing new products and services have the same underlying characteristic: complex problem solving (CPS) (Endres & Putz-Osterloh, 1994; Badke-Schaub & Buerschaper, 2001). Complex problems are frequently assigned to groups or teams (e.g. Cannon-Bowers, Oser, & Flanagan, 1992; Ellis et al., 2003). Groups are conceptualized as information processors (Hinsz, Tindale, & Vollrath, 1997) that can overcome individual information processing limitations (Tindale & Sheffey, 2002). Especially in intellective tasks, groups can outperform a number of individuals equal to the group's size (Laughlin, Bonner, & Miner, 2002; Laughlin, Gonzalez, & Sommer, 2003). Project-oriented team work is one of the most common forms of collaboration in today's knowledge-intensive businesses (Scholl, 1997). A substantial body

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of research has dealt with the relationship between information distribution and group performance and has produced mixed results (see Williams & O'Reilly, 1998; van Knippenberg, De Dreu, & Homan, 2004, for reviews), but there seems to be agreement that 'some basic level of shared or common knowledge is necessary for the group to operate' (Hinsz et al., 1997, p. 43). A certain balance between common and unique information will lead to efficient processing of information (Ellis et al., 2003).

The main body of literature that we are aware of has dealt with groups that work together on a single solution to a problem (intellective tasks); on a single decision, i.e. in mock juries or candidate selection (judgement tasks); or on an ongoing task such as complex computer or business simulations. However, as tasks are being distributed to virtual teams with substantial distances between team members (Powell, Piccoli, & Ives, 2004), situations where team members meet, share information, and then proceed with a complex problem solving task individually are common. As group level information processing affects both individual and group-level outcomes (Hinsz et al., 1997), information exchange in a group will affect individual post-exchange performance. Individual complex problem solving performance will also be influenced by previous knowledge and experience. Our aim is to model a task environment with a complex problem and to determine the effects of information distribution in the discussion of the problem on individual post-discussion performance. An understanding of optimal conditions for maximum individual gains could lead to an increase in effectiveness of learning processes among group members, which 'could offer an advantage to organizations in competitive marketplaces' (Ellis et al., 2003, p. 821).

Defining complex problems

Complex problems are characterized by the complexity of the situation, opaqueness, interconnectedness, dynamics, and polytely (Dörner, Kreuzig, Reither, & Stäudel, 1983). Kluge (2004) summarizes the findings on these five characteristics in the following way: The complexity of the situation refers to the fact that the amount of information to process is beyond individual human processing capabilities, preventing complete processing of all available information and the arrival at an optimal solution (hence the assumed superiority of groups). Opaqueness refers to the necessity of an active information search in solving a complex problem, as not all decision-relevant information is directly available. Interconnectedness refers to dependencies between the variables involved. Problem solvers have to discover dependencies between the variables that they can alter and must discover interdependency structures. Dynamics implies that the situation changes without actions by the problem solver. Polytely means that there are multiple, possibly conflicting goals to achieve. This requires 'the careful elaboration of priorities and a balance between contradicting, conflicting goals' (Funke, 2001b, p. 72).

According to Funke (2001b), these characteristics can be reduced to two main characteristics of complex problem solving: the connectivity between variables and the dynamic nature of the problem situation. Neither characteristic can be simulated using pen-and-pencil techniques, whereas the opaqueness depends largely on how the problem is presented, and complexity is mainly a result of the connectivity: 'Connectivity characterizes the structural features of the system. The dynamics bring about a procedural aspect in form of a time-dependent characteristic' (Kluge, 2004, p. 6, freely translated here); 'To summarize: in CPS research, tasks are used that consist of two specific, distinctive features, namely, connectivity and dynamics. Both attributes need a computer program for their realisation, and cannot be realized by a paper-and-pencil approach' (Funke, 2001b, p. 73). Based on the considerations mentioned above, Frensch and Funke (1995, p. 18) provide the following definition of complex problem solving (CPS):

> CPS occurs to overcome barriers between a given state and a desired goal state by means of behavioral and/or cognitive, multi-step activities. The given state, goal state, and barriers between given state and goal state are complex, change dynamically during problem solving, and are intransparent.

> The exact properties of the given state, goal state, and barriers are unknown to the solver at the outset. CPS implies the efficient interaction between a solver and the situational requirements of the task, and involves a solver's cognitive, emotional, personal, and social abilities and knowledge.

The competence to solve complex, dynamic, and partially intransparent problems can be seen as a key competence for all academic professions (Wittmann, Süß, & Oberauer, 1996). It has not been established whether complex problem solving is a unique concept or whether it is a function of problem-relevant knowledge and specific sub-scales of intelligence (Funke & Frensch, 2007).

Information pooling and performance

Problem solving groups process information similarly to individuals (Hinsz et al., 1997). Among other information-processing tasks, groups need to focus their attention on certain information in order to process it. The distribution of information among group members is important, because 'the distribution of information in a group influences what information becomes the focus on attention' (Hinsz et al., 1997, p. 46).

Findings by Stasser and colleagues (Stasser, Taylor, & Hanna, 1989; Stasser & Stewart, 1992) indicate that shared information is more likely to enter the discussion than unique information (i.e. it is more likely to be processed). This phenomenon is referred to as the 'common knowledge effect' (Tindale & Sheffey, 2002). It is especially harmful in situations where the shared information indicates a different (and possibly worse) group decision than the unshared information (so-called hidden-profile tasks, Stasser & Titus, 1985, 1987).

Groups seem to be 'less prone to overlooking unshared information if they believe that their task has a demonstrably correct answer' (Stasser & Stewart, 1992, p. 426). Structuring discussions also increases the amount of information discussed (Stasser et al., 1989). However, neither of these conditions is likely to be met in unstructured work-related complex problem solving. Thus, high informational overlap in groups that work together on unstructured complex tasks seems beneficial for group performance. This finding has been replicated with different tasks in different contexts (e.g. Larson, Christensen, Franz, & Abbott, 1998; Rulke & Galskiewicz, 2000; Tindale & Sheffey, 2002; Ohtsubo, 2005) and suggests a linear relationship between informational overlap and group performance.

The benefit of information exchange among group members lies in the transfer of knowledge and skill from one group member to others (Gruenfeld, Martorana, & Fan, 2000). This team learning is a 'relatively permanent change in the team's collective level of knowledge and skill produced by shared experience of the team members' (Ellis et al., 2003, p. 822). These processes affect not only group-level outcomes but also individual-level outcomes (Levine, Resnick, & Higgins, 1993). We thus postulate:

> Hypothesis 1: The amount of group learning in a group discussing a complex problem has a positive influence on individual post-discussion complex problem solving performance.

Group learning requires a shared frame of reference (Ellis et al., 2003). Shared frames of reference require a certain degree of shared knowledge (Polanyi, 1958, 1966). At the same time, some heterogeneity in knowledge is also required for team learning, because nothing can be learned otherwise. Thus, apart from a shared frame of reference, some heterogeneity in group-level information distribution is required for individual benefits from team learning, which—contrary to the above-mentioned findings—indicates a *curvilinear* relation between information distribution on the one hand, and team learning and group performance on the other:

> To benefit from the diversity of information, expertise, and perspectives that may be associated with dimensions of differentiation, group members should be able to understand and integrate the contributions of dissimilar others. As group members differ more in background, experience, and expertise, however, it becomes more likely that they do not share a common frame of reference (i.e. 'speak the same language') that allows in-depth

> understanding of diverse others' input. Thus, the potentially positive effects of diversity on group performance may only obtain up to a certain level of diversity, beyond which the lack of a common frame of reference may get in the way of fully appreciating all group members' contributions. (van Knippenberg & Schippers, 2007, p. 532)

If individual post-discussion performance is related to team learning (Hypothesis 1), and team learning is a curvilinear function of information distribution, individual performance must also exhibit a curvilinear relationship with information distribution.

Scholl's (1996, 2005) model of team effectiveness also argues that knowledge increase through discussion depends on the cognitive heterogeneity among group members: If it is small, there is little that people can learn from each other, and if it is large, process losses due to communication difficulties prevent group-level knowledge increase through learning (see Figure 1). We postulate:

> Hypothesis 2: There exists an inverse u-shaped relation between information overlap in a group and the amount of group-level knowledge increase through information exchange.

As we assume that the individual benefit of team learning is positively correlated with the amount of team learning (compare Hypothesis 1), we postulate:

> Hypothesis 3: There is an inverse u-shaped relation between the heterogeneity of information in a group and individual complex problem solving performance after information exchange.

Experience in CPS

Individual features influence complex problem solving (Endres & Putz-Osterloh, 1994).

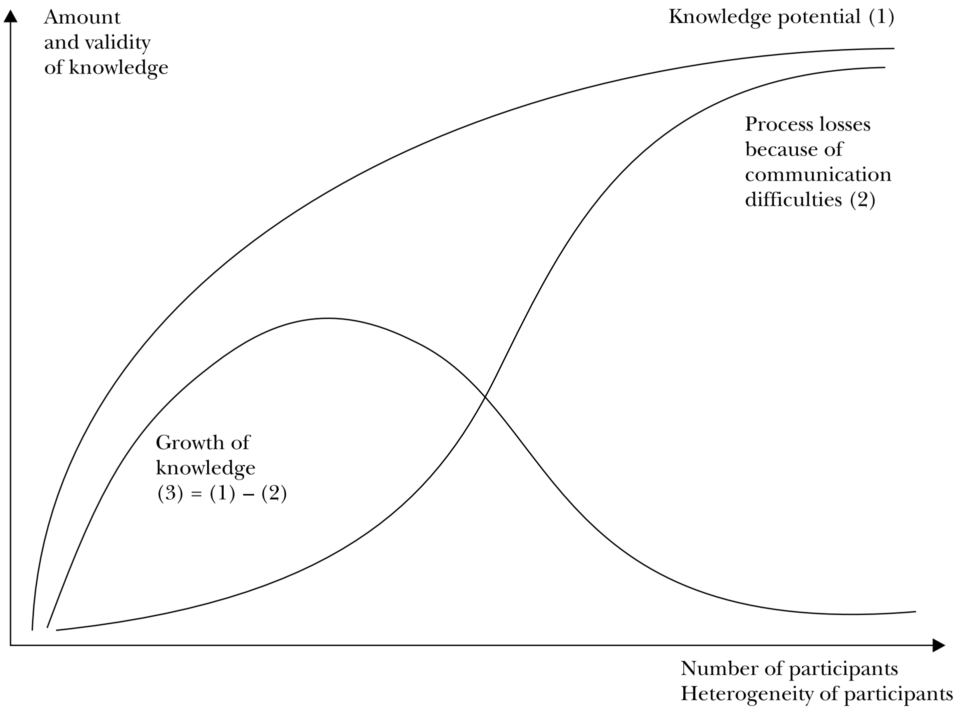

Figure 1. Assumed relationship between informational heterogeneity of participants, amount of knowledge, and knowledge increase.

Source: Adapted from Scholl (1996), p. 137.

Studies identified domain-specific declarative knowledge and intelligence, especially reasoning, as influencing complex problem solving performance (Funke, 1992; Süß, 1996; Kersting & Süß, 1995; Kersting, 1999; Quesada, Kintsch, & Gomez, 2002; Funke & Frensch, 2007; Kluge, 2008). Implicit knowledge has also been suggested to predict CPS performance (Berry, 1991; Berry & Broadbent, 1995; Buchner, Funke, & Berry, 1995). Implicit knowledge can be defined as 'performance advantages in the accomplishment of cognitive requirements, which are based on an unconscious use of previously perceived and unintentionally stored information' (Kluwe, 2006, p. 41, freely translated here). It is thus closely related to implicit memory processes, which retrieve specific events or experiences 'without making the actual content and its meaning conscious' (Markowitsch, 1999, p. 25, freely translated here).

Implicit knowledge is acquired through action, experience, and learning by doing (Nonaka & Konno, 1998). Hands-on experience with a complex problem usually leads to increased performance in that particular problem (Süß, 1996). If the performance increase through experience is dissociated from an increase in articulable knowledge, one can assume that the experience with the problem induced implicit knowledge. Such dissociations were reported in some studies (Berry, 1984; Berry & Broadbent, 1995), but the employed problems were rather simple and other reasons could have led to the observed effects (Berry & Broadbent, 1995). However, Dorfman, Shames, and Kihlstrom (1996) also support the importance of implicit knowledge in CPS performance by stating that intuition and insight also account for CPS performance, which they assign to the implicit domain. Experimental support for the importance of implicit knowledge in CPS performance is so far limited to Berry and Broadbent's work. It will thus be put to another test, as we assume that experience with a complex problem scenario leads to an increase in CPS performance that is dissociated from an increase in articulable scenario knowledge.

Hypothesis 4: Experience with a complex problem increases problem solving performance without increasing articulable knowledge on the problem in question.

The present study

Overview

We chose to examine complex problem solving performance of individuals assigned to dyads under different conditions of informational overlap and experience with the complex problem.

In the psychological laboratory and in personnel selection processes, the ability to solve complex problems can be tested using so-called dynamic scenarios or microworlds (MWs) (Funke & Frensch, 2007; Kluge, 2004, 2008). MWs are computer simulations that 'use a cover story (e.g. a small town, an airport, or a tailor's shop) and are composed of many interrelated components, variables, and functions (Badke-Schaub & Strohschneider, 1998)' (Kluge, 2008, p. 158). Up to 60% of German firms employ simulation techniques of this kind for upper and middle management selection (Schuler, Frier, & Kaufmann, 1993).

We chose the Tailorshop (*Schneiderwerkstatt*) microworld (Süß & Faulhaber, 1990, Süß, 1996, Wittmann et al., 1996) as an operationalization of complex problem solving ability for four reasons. First, Kluge's (2004) analysis of the reliability and validity of several available microworlds placed Tailorshop in first place. Second, performance scores in the Tailorshop microworld correlated positively with performance in other microworlds (Wittmann et al., 1996). Third, Tailorshop performance scores predicted job performance (Kersting, 1999), which indicates generalizability. Fourth, there exists a validated questionnaire on Tailorshop-relevant declarative knowledge (Kersting & Süß, 1995).

In our study, we provide information on successful microworld control to both members of a dyad for individual learning and manipulate the extent to which the information overlaps. Since we are interested in the effects of information overlap on performance, we keep the individual cognitive load per participant at equal levels. If information overlap and the amount of information administered to a participant were confounded, it would be difficult to judge whether differences in individual performance stem from a characteristic of the group (information overlap) or from individual members' learning abilities. We thus keep individual characteristics at a constant level in order to determine effects on group level at the group level. Furthermore, effects of sympathy and interpersonal liking could interfere with the effects of information distribution. In accordance with Heider's balance theory (Heider, 1958), a perceived similarity in knowledge is likely to lead to feelings of sympathy. Feelings of sympathy influence interpersonal agreement (Klocke, 2007) and could thus affect performance if individuals work together on the microworld. Effects of sympathy and information distribution could not be disentangled.

After individual learning, participants are tested on microworld-relevant knowledge and are then asked to discuss what they have learned. After the discussion, participants are tested on microworld knowledge again, and they work on the microworld individually afterwards. As microworld performance is also known to correlate with reasoning ability, a reasoning scale is also administered.

In order to manipulate experience with the system, we provide a computer running the Tailorshop to one half of the participants during individual learning. In this way, they can familiarize themselves with the program interface and try the program out. They can make alterations to the variables covered in their tests and advance through a few months in order to see how their actions affect the variables. Half of the participants have a computer running the Tailorshop microworld available during their discussion. They can test possible hypotheses on modes of operation during the discussion before working on the system individually. Thus, a quarter of the participants will work with the Tailorshop scenario twice before the actual problem solving task: once during individual learning, once during the discussion. One quarter will try out Tailorshop only during individual learning, one quarter only during the discussion and one quarter will perform the individual problem solving task without prior exposure to the computer program.

Method

Participants and design

The study took place at the Institute of Psychology at Humboldt University, Berlin. It was advertised as an assessment center (AC) simulation, as it involved typical elements of an assessment such as an IQ test, a group discussion, and a complex management computer simulation. Participants were offered detailed feedback on their performance, and the top ten teams were offered a reward of 10–15 EUR per member, depending on their performance. The participants were 150 persons, mostly students from different fields and different universities in Berlin, forming 75 dyads. We chose dyads in order to minimize social effects that occur in larger groups and due to the fact that dialogue is considered to be one of the most powerful forms of learning and knowledge sharing in problem solving (Hausmann, 2005). Participants were assigned randomly to dyads and to experimental conditions. Four dyads were excluded due to technical failures (performance scores were not saved for either member), and four dyads due to failure of at least one participant to complete all pages of all questionnaires. The remaining effective sample size was 134 individuals (70 women and 64 men) in 67 dyads. The experiment employs a 3 (full information overlap—partial information overlap—no information overlap) × 4 (no practical experience with the microworld—experience during learning—experience during discussion—experience during learning and discussion) factorial design.

Complex problem-solving task

The Berlin version of the Tailorshop microworld (the A-Version in Süß, 1996) we employed puts the participant in the role of manager of a small shirt factory. The participant is told to increase the company's value by making alterations to twelve input variables over a period of twelve turns (each turn simulates a month). In each month, twelve variables can be altered by the participant: purchase of raw material for shirt production, market price for shirts, marketing budget, number of shops, number of traveling salesmen, number of small shirt-producing machines (producing 50 shirts per month), number of large shirt-producing machines (producing 100 shirts per month), number of workers for each type of machine, machine maintenance budget, wages, and social welfare. The changes made to these variables influence the values of the observable variables total assets, account balance, raw material price, demand, shirts in stock, sold shirts, production, production downtime, damage to machines, load factor (machines), load factor (workers), and workers' motivation. Input variables, planned changes to input variables, output variables, and their current state are displayed in text form by the computer program (Figure 2).

The underlying structure of the Tailorshop microworld is a linear structural model (Funke, 2001a). The state of the output variables in a given turn is combined in a positive or negative way with the values of the input variables, if the participant chooses to advance one turn. This linear combination produces the output variables displayed at the beginning of the next turn. In order to add a dynamic element to the system, the price of raw material in each turn is determined by chance independently of other variables. To add further complexity to the system, the underlying causal structure includes ten invisible variables. The connection scheme of underlying variables is presented in Figure 3.

Figure 3 illustrates that all input variables have an indirect effect on the total assets. A holistic understanding of the system will likely lead to successful strategies, but partial knowledge of system relations does not necessarily induce higher performance (Preußler, 1998). A successful strategy would be to take early and strong measures that will increase demand, e.g. by increasing spending on advertising, by increasing the number of outlets, and by

This is the state of your company at the end of month 0

	Plan	Current		Current
Raw material		583	Total assets ($)	112139
Shirt price ($)		84	Account balance ($)	30119
Advertising ($)		1850	Raw material price ($)	4.00
Outlets		1	Demand	129
Travelling salesmen		2	Shirts in stock	417
50s–Machines		6	Sold shirts	129
100s–Machines		3	Production	465
Maintenance ($)		630	Production downtimes (%)	42
Workers on 50s		3	Damage to machines (%)	8
Workers on 100s		4	Load factor (Machines) (%)	78
Wage ($)		1530	Load factor (Workers) (%)	85
Social costs ($)		35	Worker's motivation (%)	75

You can:
Buy raw material for shirts

Possible actions
↵ Select menu item
↓ Next menu item
↑ Previous menu item

a Execute plan

Remaining time: 45 minutes

Figure 2. Schematic and translated interface of the Tailorshop microworld.

Notes: The input variables are displayed in the left column, the output variables are displayed in the right column. Users can select the input variable that they wish to change using the arrow keys (in this figure, raw material is selected). Pressing the enter key brings up a dialog box (not depicted). After all the desired changes are made, the user presses the 'a' key in order to execute the planning. Pressing the 'a' key advances the system one turn (i.e., one simulated month) and updates the output variables to incorporate the changes made.

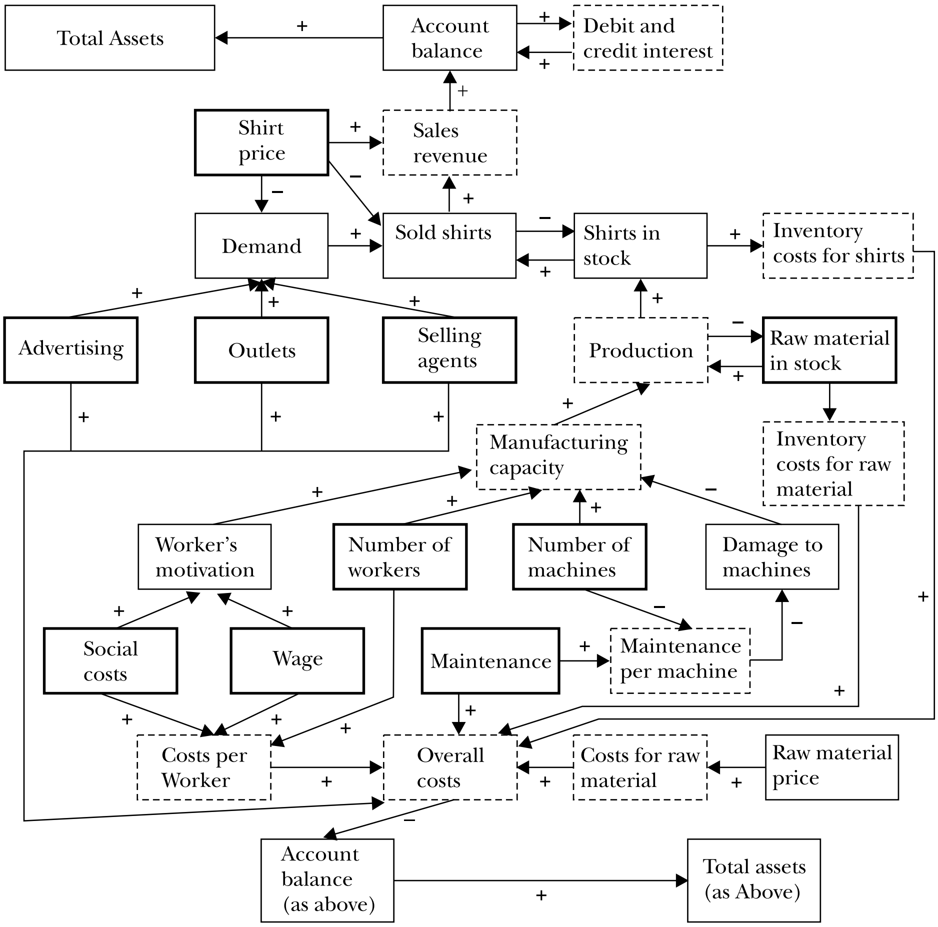

Figure 3. Scheme of causal influences among Tailorshop variables.

Notes: Dashed boxes indicate invisible variables, solid boxes indicate output variables, and bold boxes indicate input variables that the user can alter. The number of workers and the number of machines are both included twice (for machines producing 50 shirts per month and for machines producing 100 shirts per month).
Source: Adapted from Süß (1996), p. 102.

increasing the number of selling agents. The number of machines producing 100 shirts per month would be equally increased to meet the demand as closely as possible (machines producing 50 shirts a month should be traded for machines producing 100, because they produce the same costs at half the output). There should be one worker per machine. If a high constant demand that can be matched with the production is achieved, raw material that matches the demand of the previous month should be bought each month regardless of its price, keeping inventory costs at a minimum. Wages and social security expenditure should be adjusted in such a way that workers' motivation reaches 100%. Spending on maintenance should be adjusted in such a way that damage to machinery does not increase over a one-digit number. In summary, costs should be minimized while profits should be maximized. If the system can be brought to equilibrium of this kind at an early stage in the simulation, the remaining turns can be used to increase earnings and profit. The overall profit that participants are able to achieve (calculated as the total assets at the end of the simulation minus the total assets at the beginning of the simulation) serves as the dependent variable operationalizing task performance.

Procedure

Fourteen student experimenters formed teams of two experimenters; one team conducted a given session. Experimenters greeted participants upon arrival and introduced them to the laboratory and the course of the experiment. After the introduction, each participant worked individually on the reasoning scale of the short form of the Berlin Structural Intelligence Test (BIS-K) (Jäger, Süß, & Beauducel, 1997), because reasoning is one underlying factor likely to determine Tailorshop scenario performance (Süß, 1996).

Manipulation of information overlap After the BIS Test, individual learning took place. During learning, participants individually acquired knowledge on Tailorshop scenario control from instructional texts developed by Klocke (2004). In our study, we assigned sections of Klocke's instructional texts to labels G1, G2, A, B, C, D, E, F, G, H, I, and J, where G1 and G2 represent general, introductory information on the system and elements A–J encompass specific knowledge elements on how to perform successfully (see Table 1).

Each participant received items G1 and G2 and five Items from the set A–J, embedded into running text for learning. For the latter learning text, the intra-group overlap between group members was experimentally varied. In the fully overlapping condition, both group members received the same five elements. In the partially overlapping condition, two of the five elements were assigned to both group members, and three elements were exclusive to each member. In the no-overlap condition, each group member received five text paragraphs that the other members did not receive. Note that cognitive load was about the same for the individual group members over all conditions (two general paragraphs G1 and G2 plus five specific paragraphs), but the number of unique paragraphs within the dyad differed. Apart from the general elements G1 and G2, there were five unique paragraphs in the overlapping condition, eight unique paragraphs in the partially overlapping condition, and ten unique paragraphs in the no overlap condition. Learning took place individually, and the learning time was ten minutes. Participants were allowed to take notes at their discretion during learning. Thus, the amount of unshared information available to group members leads to a larger amount of information available on the group level. This is exactly the advantage of group discussion over pure individual problem solving.

Due to the connectionist structure of the existing instructional text edited by Klocke (2004), it was not possible to present each knowledge element independently of the others, as some of the text passages refer to each other. The following combinations of knowledge elements could be formed without rendering the text illegible: ABCIJ, DEFGH, BCDEF, and EFGHI. Dyads in the no overlap condition received texts containing elements ABCIJ and DEFGH, dyads in the partial overlap condition received texts containing BCDEF and DEFGH, and dyads in the overlapping condition received a random set of two identical texts. Note that the fully overlapping condition serves as a baseline condition. If the amount of information in the dyad determines individual post-discussion performance, individuals from the no-overlap condition should exhibit a significantly higher performance. If a curvilinear relationship is present, the partial overlap condition should lead to higher performance compared to the overlap condition.

The question as to whether the combinations of text paragraphs are individually of equal worth for performance is addressed in the results section below. The text was two pages in length and included a picture of the Tailorshop interface as well as the initial state of the scenario. This enabled the participants to discuss possible strategies for the alteration of the

Table 1. Information on successful Tailorshop scenario control embedded in instructional texts based on Klocke (2004)

Element	Title	Content
G1	Stable system	Small changes lead to small consequences; do not act too cautiously. The bank offers generous credit and a negative value on the bank account is not a problem. If in financial trouble, do not sell assets such as machinery and shops.
G2	Equilibrium	The demand should meet production: the number of machines should be equal to the number of workers; you should continuously increase sales, and expand business.
A	Raw material	The price of raw material on the market is independent of all other variables and is subject to market fluctuations. There should always be enough raw material in stock to meet production capacity.
B	Stocking	Stocking creates costs. Do not produce too much but enough to satisfy market demand.
C	Production and demand	The number of shirts in stock plus raw material should equal demand. If the demand is unequal to production, it is better to increase one variable instead of decreasing it.
D	Investment strategy	In order to pay off investments such as new machinery and new shops, they should be made at an early point in time.
E	Machine efficiency	Displays (in percent) usage of machinery capacity. If the value falls below 100%, machines may be damaged, may have too few operators, workers may not be motivated, or too little raw material may be present.
F	Worker efficiency	Displays (in percent) usage of work capacity. If the value falls below 100%, workers may not be motivated (depending on wages and welfare), or too little raw material may be present.
G	Investing in machinery	You should only buy machines that produce 100 shirts per month, as these produce the same costs in maintenance as machines producing 50 shirts a month.
H	Damage to machinery	Spending on machinery maintenance prevents damage and should never be 0. If damage rise above 10%, maintenance should be increased. More machines require more maintenance, and damage to machinery is independent of workers' motivation.
I	Demand	The advertising budget, the number of shops, and the number of selling agents increase demand. The shirt price has a stronger influence on demand than marketing.
J	Expenses	Advertising budget, the number of shops, the number of selling agents, stock, and expenses per worker (wages and welfare) increase costs and reduce profit.

Note: Original text was in German.

unfavorable initial state of the factory in the discussion part that followed at a later stage of the experiment.

Manipulation of scenario experience In order to induce a possible dissociation between performance and articulable knowledge, half of the participants had a laptop computer running the Tailorshop simulation available during individual learning. They were told that they could make alterations to the input variables that were covered in their texts. An experimenter stood behind the participant in order to make sure that only those variables were altered. The available Tailorshop was running in training mode. That meant that initial variable values were different from the initial variable values in the final task and only two turns could be taken. In this way, participants acquired hands-on scenario experience through learning-by-doing and were expected to gain more experience with the microworld compared to those participants who learned only from texts.

After completing a set of questionnaires (see below), participants were seated together at a table and were asked to discuss what they had learned and to teach each other as much of their acquired knowledge as possible. Participants were told that their performance would be assessed after the experiment on the basis of the mean of all individual performances and were thus motivated to actually share their knowledge. Participants were allowed to bring their notes to the discussion and to make further notes. The time allowed for discussion was 15 minutes, and the discussion was not structured in any further way. The instructions emphasized the aspect of knowledge exchange, which aimed at keeping normative influences to a minimum and at maximizing informational processes. In half of the dyads, a laptop computer running the training mode of the Tailorshop microworld was placed on the table. In this way, participants were able to test their hypotheses on modes of operation during the discussion.

The discussion setting can be seen as a viable operationalization of situations occurring in organizational practice: Two individuals freely discuss a complex problem in a 15-minutes meeting and take notes and then proceed with individual work afterwards. The discussion was filmed on video.

Measures After individual learning, participants performed a self-assessment: For each title of the ten specific knowledge elements, they were asked to assess their own level of knowledge on a scale with four response alternatives (nothing or very little/some/medium/good). Participants were also asked to rate their computer experience and the degree of their prior economic knowledge on a 5-point Likert scale, as these features influenced problem solving capabilities in other studies (Süß, 1996). After self-assessment, participants completed the short version of the questionnaire on Tailorshop scenario declarative knowledge (Klocke, 2004). The short questionnaire consists of three scales: variable relations (thirteen boxes, each box contains six statements concerning relationships between two specific variables that have to be marked as true or false, e.g. 'Increasing production increases shirt price'), features of variables (six true/false statements with reference to one variable per item, e.g. 'Demand increases and decreases on its own', four items), and rules of thumb (21 items with true/false/I don't know response alternatives, e.g. 'There should be more workers than machines'). Participants were not allowed to use their notes during the test.

After the discussion, the participants filled out the short version of the Tailorshop knowledge questionnaire for a second time (again, the use of notes was not permitted). This second test allows the quantification of the individual knowledge increase caused by the discussion. Participants also completed a scale on the quality of knowledge exchange (four items, e.g. 'I feel that I properly conveyed my knowledge on Tailorshop to my discussion partner', 'My discussion partner properly conveyed his/her knowledge to me', response scales with four response alternatives ranging from 1 = not at all to 4 = absolutely, Cronbach's alpha = .90).

Finally, participants worked on the Tailorshop microworld individually but were allowed to use their notes. The time limit was 60 minutes. Afterwards, participants were thanked and debriefed. The experiment lasted approximately two hours.

Results

Manipulation check

In order to test whether the manipulation of information distribution was successful, we calculated the distance between the participant's Tailorshop knowledge self-assessment in each dyad (Kenny, Kashy, & Cook, 2006). The distance is a vector with ten elements; each element is the absolute value of the difference of the two individual responses to the same item on the self-assessment questionnaire in one dyad. One element of the vector can thus range from 0 to 3.

The elements of the vector are summed up and divided by the possible maximum (30). In this way, the distance in self-assessment is a number between 0 and 1. 1 indicates a maximum difference in knowledge self-assessment between the two group members; 0 indicates a perfect overlap of knowledge self-assessment. If the manipulation in terms of knowledge overlap within the dyad was successful, groups in the no overlap condition should exhibit a larger distance than groups in the partial overlap condition, who again should display a larger distance than groups in the overlapping condition. This pattern is visible in the data (see Figure 4), and a one-way analysis of variance of the distance over the factor information distribution yielded significant results ($F(2, 64) = 4.688$, $p = .013$, $\eta^2 = .132$).

Comparability of learned information

In order to test whether participants had a comparable amount of scenario knowledge after learning the five Tailorshop text elements and to make sure that no combination of text paragraphs was superior to others, we tested whether all combinations of text paragraphs employed (ABCIJ, DEFGH, BCDEF, and EFGHI, compare Table 2) led to comparable pre-discussion knowledge scores on the Tailorshop knowledge questionnaire. A one-factor ANOVA of knowledge scores over the four combinations of knowledge elements revealed no significant effect of the learned knowledge element on individual pre-discussion Tailorshop knowledge ($F(3,130) = 0.339$, $p = 0.80$). Thus, on the individual level, all participants entered the experiment with comparable amounts of declarative knowledge across the learning variations, and no specific combination of text paragraphs led to superior knowledge on microworld control.

Analysis of nonindependence

If the two scores of participants in a dyad are more similar to one another than two scores of participants who are not members of the same

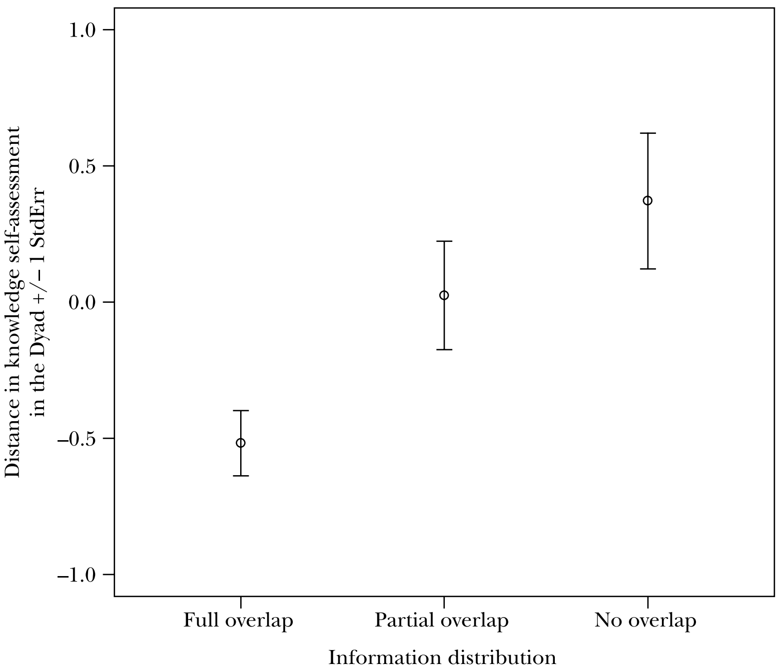

Figure 4. Distance of tailorshop knowledge self-assessment in the dyad over information distribution condition.

Table 2. Hierarchical regression of Tailorshop profit on independent variables

Predictors of tailorshop profit	*B*	*SE*	β	*t*	*p*
Step 1					
Reasoning	.03	.03	.15	1.02	.311
Computer experience	–.26	.22	–.16	–1.19	.239
Economic knowledge	.22	.16	.18	1.14	.171
Pre-discussion knowledge	.03	.02	.16	1.05	.298
Step 2					
Reasoning	.02	.03	.12	0.83	.413
Computer experience	–.31	.20	–.19	–1.52	.134
Economic knowledge	.32	.15	.26	2.11	.039
Pre-discussion knowledge	.04	.02	.27	1.85	.069
Post-discussion knowledge increase	.10	.03	.37	3.05	.003

Notes: Dyadic average, $N = 67$.
Adjusted $R^2 = .05$ for step 1, adjusted $R^2 = .16$ for step 2, $\Delta R^2 = .12 (p = .003)$.

dyad are, they are nonindependent (Kenny et al., 2006). A nonindependent variable may not be analyzed on the individual level without taking the nonindependence into account (Kenny et al., 2006). We therefore analyzed the dependent variables elicited after the interaction, namely, post-discussion Tailorshop knowledge and Tailorshop profit, for nonindependence, because one participant's score in these variables may be influenced by the information that he or she received from the study discussion partner. As we do not distinguish between participants, members of the dyad are indistinguishable. In that case, nonindependence has to be analyzed using the intra-class correlation coefficient (ICC) (Kenny et al., 2006). We employed the method for calculating the ICC suggested by Alferes and Kenny (in press). The post-discussion Tailorshop knowledge score exhibited an ICC of .25 ($p = .040$); for Tailorshop profit, the ICC was .37 ($p = .002$). Both variables are thus nonindependent, i.e. their individual realization is partly based on interaction processes in the dyad. This is an expected and experimentally desired sign of learning through discussion. As participants cannot be analyzed on the individual level, we averaged them on the dyad level (Kenny et al., 2006).

Time constraints

Although we felt that a time period of 15 minutes was ample for discussing the information learned, time constraints in the discussion may have prevented the exchange of all relevant information in the no overlap condition. In order to test whether time constraints played a role in information exchange, we conducted two analyses. First, we analyzed the quality of knowledge exchange. As nonindependence is present (ICC = .25, $p = .040$), scores on this scale were averaged on the dyad level. A two-factor univariate ANOVA of the factors' information distribution (shared, partly shared, unshared) and exchange mode (scenario present in the discussion/not present) on the quality of knowledge exchange revealed no significant main effects (knowledge distribution: $F(2,61) = 1.089$, $p = .343$, exchange mode: $F(1,61) = 1.000$, $p = .390$) and no significant interaction ($F(2,61) = .655$, $p = .256$).

Second, we coded the videotapes of the discussion and counted, on the group level, how often either of the discussants mentioned the text elements that had been provided. Of the 67 coded recordings, 22 were randomly selected and were coded twice by two of seven student coders. Inter-rater reliability of the frequencies between coders was determined for each text element. Cronbach's alpha over all elements was .67 and deemed acceptable.

We divided the number of text elements that were not mentioned at all in the discussion by the number of total text elements previously provided to either group member. If time constraints had prevented participants in the no overlap condition from sharing the previously acquired information, the percentage of unmentioned text elements should be higher in the no overlap condition than in the partial and in the full overlap condition. A two-factor univariate ANOVA of the factors information distribution (shared/partly shared/unshared) and exchange mode (scenario present in the discussion/not present) on percentage of unmentioned elements revealed a marginally significant main effect of knowledge distribution ($F(2,61) = 2.553$, $p = .086$, $\eta^2 = .073$), no significant main effect of exchange mode ($F(1,61) = .543$, $p = .464$), and no significant interaction ($F(2,61) = .377$, $p = .688$). We examined the differences in means over the knowledge distribution more closely using post-hoc Scheffé tests. The tests revealed no significant differences in percentage of unmentioned texts between the overlapping condition ($M = .19$) and the no overlap condition ($M = .17$, mean difference = .02, $p = .871$). Only the difference between the partly overlapping condition ($M = .10$) and the full overlap ($M = .19$) was close to marginal significance (mean difference = .09, $p = .116$).

Thus, dyads under the unshared condition omitted as little given information as dyads in the shared condition, although they had twice as much material for exchange in the dyad. Combining these findings with the above-mentioned results of the scale on the quality of knowledge exchange, neither observational data nor self-report data indicate that time constraints prevented dyads in the unshared condition from exchanging relevant information.

Learning and performance

Hypothesis 1 assumed a relation between the amount of group learning in a group discussing a complex problem and individual post-discussion complex problem solving performance. The above analysis of nonindependence revealed that individual post-discussion knowledge and complex problem solving performance depend on previous interactions. Thus, performance scores cannot be related with post-discussion knowledge on the individual level. We thus employed dyadic average scores instead. In order to test the hypothesis, we performed a hierarchical regression analysis. The first step included the established predictors of individual complex problem solving performance: reasoning ability, computer experience, prior economic knowledge (Süß, 1996), and pre-discussion Tailorshop knowledge. As the dependent variable Tailorshop profit is averaged on the dyad level, so were the independent variables. The second step added the dyadic average of Tailorshop knowledge increase (computed as post-discussion knowledge minus pre-discussion knowledge) to the model. We employed the knowledge increase instead of the post-discussion score due to collinearity concerns. The regression (see Table 2) revealed that the amount of learning has the strongest influence on Tailorshop profit and explained an additional 12% of its variance. Hypothesis 1 thus received support. Although the dyadic average of reasoning exhibited a significant bivariate correlation with Tailorshop performance ($r = .24$, $p = 0.46$), its influence on the dependent variable dropped below levels of statistical significance in the regression. Neither computer experience nor prior economic knowledge correlated with Tailorshop performance ($r = .15$, $p = .120$ and $r = .04$, $p = .387$).

Information overlap and learning

In order to test Hypothesis 2 (an inverse u-shaped relation between information overlap in a group and the amount of group-level knowledge increase), we performed a one-way analysis of variance with linear and quadratic polynomial contrasts of the effect of information distribution on post-discussion knowledge increase. The combined model did not reach significance ($F(2,64) = 1.525$, $p = .225$, $\eta^2 = .045$), nor did the linear term ($F(1,64) = .019$, $p = .892$, $\eta^2 = .000$). The quadratic term exhibited a marginally significant effect ($F(1,64) = 3.073$, $p = .086$, $\eta^2 = .045$). The pattern of the data followed the prediction of the inverse u-shaped connection between information overlap within the dyad and knowledge increase (see Figure 5). The hypothesis received marginal support.

Information overlap and CPS performance

Hypothesis 3 assumed an inverse u-shaped relation between the heterogeneity of information in a group and individual complex problem solving

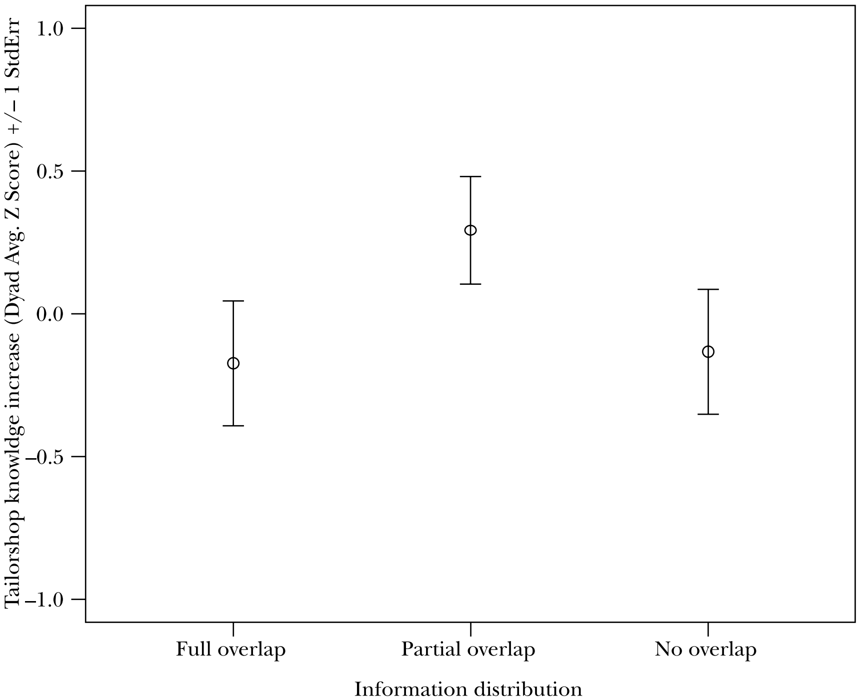

Figure 5. Group learning operationalized as average dyadic difference between pre-discussion knowledge test to post-discussion knowledge test over information distribution condition.

performance after unstructured information exchange (discussion). A one-way analysis of variance with linear and quadratic polynomial contrasts of the effect of knowledge distribution on Tailorshop performance revealed a significant combined effect between groups ($F(2,64) = 5.053$, $p = .009$, $\eta^2 = .136$), a marginally significant effect of the linear term ($F(1,64) = 3.452$, $p = .068$, $\eta^2 = .047$), and a significant quadratic effect ($F(1,64) = 6.907$; $p = .011$, $\eta^2 = .093$) as Figure 6 shows. Hypothesis 3 thus received support.

Experience and CPS performance

In order to test whether experience with the microworld during the experiment led to a performance increase (Hypothesis 4) and in order to check for possible interactions between experience and information distribution, we performed a two-factor ANOVA with the factors' information distribution (shared, partly shared, unshared) and experience (none, during learning, during discussion, during both). It revealed a significant main effect of information distribution ($F(2,55) = 4.227$, $p = 0.20$, $\eta^2 = .12$), no significant main effect of experience ($F(3,55) = .340$, $p = .792$) and no significant interaction ($F(6,55) = .367$, $p = .897$). Hypothesis 4 was refuted, because its sine qua non, a relation between experience an performance, was not present.

Discussion

One goal of the study was to determine how information distribution in a discussion prior to a complex problem solving task would affect individual post-discussion complex problem solving performance. An inverse u-shaped relationship between information overlap and performance was obtained. Consistent with

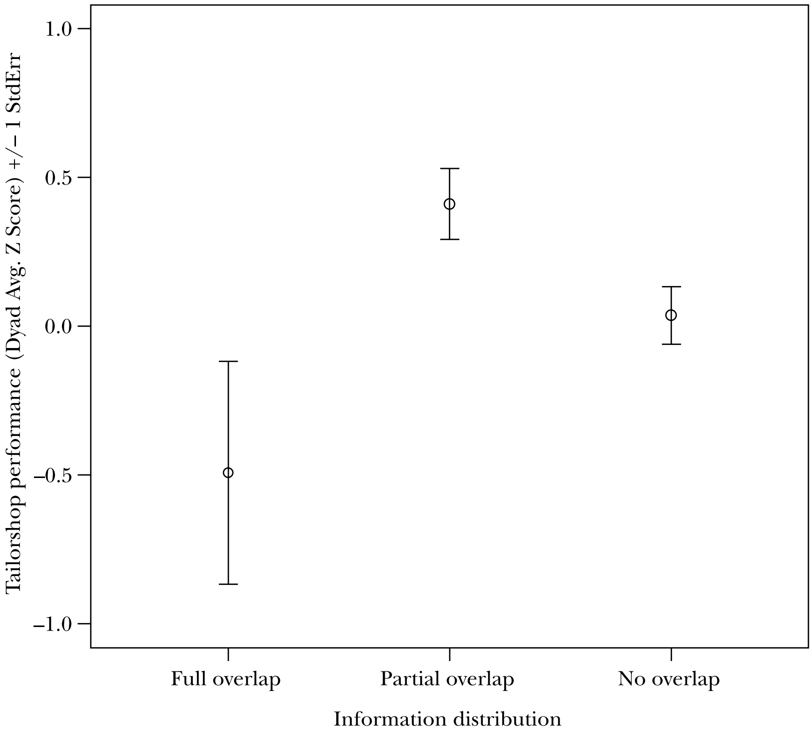

Figure 6. Dyadic average Tailorshop performance score (profit) over information distribution condition.

the hypothesis, this analysis suggests that a medium informational overlap in a group leads to highest levels of group learning. The more learning that occurs on an average level among group members, the higher the individual post-discussion performance. Average group learning, operationalized as average group member knowledge increase through discussion, was highest if a medium information overlap was present among group members prior to the discussion.

The results show that individual performance in this experiment is not primarily a function of the amount of knowledge inherent in the dyad, but a function of the knowledge distribution within the dyad. However, the observation that dyads operating under the no overlap condition with ten unique specific text paragraphs in the dyad outperformed dyads working under the overlap condition (five specific unique text paragraphs) indicates that the amount of information contained in the dyad is not negligible. However, the quadratic effect that we attribute to information overlap was double the size of the linear effect that we attribute to the amount of information contained in the dyad.

The results do not support the 'common knowledge effect' (Tindale & Sheffey, 2002) in individual complex problem solving after a discussion. If only shared information had been exchanged in the discussion, groups with partially overlapping information (three unique specific text paragraphs available to both group members) should have exhibited equal or lower performance than those groups having fully overlapping information (five unique specific paragraphs available to both members). The contrary was observed: Groups with partially overlapping information achieved higher performance and learning scores than the other groups. Thus, when discussing complex problem solving strategies, partially overlapping information is superior to fully overlapping information—under the condition that the amount of individual knowledge of group members is roughly equal.

Another goal of the study was to determine whether experience in complex problem solving leads to higher problem solving performance. This hypothesis is based on the premise that implicit knowledge is necessary for CPS and that using the microworld allows implicit knowledge to be acquired. However, our findings did not support it. The finding that neither scenario experiences during learning nor the availability of a scenario during discussion influenced scenario performance in a significant way contradicts other findings (Berry & Broadbent, 1995; Süß, 1996). We offer two possible explanations for our results: First, experience with the system could have led to other forms of knowledge that may have only little influence on scenario control. Second, the available time during learning and interaction might have been too limited to allow the formation of implicit knowledge. This possibility appears to be the most plausible. According to Kluwe, Haider, and Misiak (1990), contrary effects—i.e. a performance decrease after experience with a scenario—can occur if the scenario was presented too briefly. As Süß (1996) found effects only for male participants after 30 minutes of scenario exposure, our maximum interval of 25 minutes (ten during individual learning, 15 during discussion) might have been too short. Further studies on the exact preconditions of the effect of experience on performance are warranted.

One important issue with the current study lies in the fact that we did not study 'group-level' problem solving. The participants did not work together on the task but instead worked as separate entities. The analysis of nonindependence revealed that group members worked in a similar way on the individual task after the discussion (hence the significant intra-class correlation), but this is still different from working together on the task. We thus employed a collective approach: '[T]he collective approach targets the knowledge of individual team members and then aggregates this information' (Cooke, Salas, & Stout, 2000, p. 164). In this setting, phases of information exchange and phases of task execution were separated. Although groups go through several phases during problem solving processes (Bales & Strodtbeck, 1951), information exchange and task execution take place simultaneously in group-level CPS. As we were interested in the effects of information exchange, this design limited the possibility of other effects of group interaction interfering with effects of information distribution.

This feature of our study prevents extension of our findings to groups interacting on a problem. Task execution can interfere with interaction processes, and additional process losses can occur due to interaction phenomena (Endres & Putz-Osterloh, 1994). We see the outcome of the discussion with overlapping information on learning and individual performance as a sine qua non for analyzing the effects of information overlap. The fact that we did find the effect justifies further studies aimed at extending our findings to groups working together on a complex problem. Further studies should also extend the results to larger groups.

Time constraints did not seem to limit the amount of information verbally articulated by study participants during the discussion. However, it is possible that further opportunities for exchange and collaboration for participants under the unshared condition would have allowed them to benefit from their heterogenous knowledge to a further extent. As groups working together over a longer period of time and coming together on several occasions can learn more over time (Brodbeck & Greitemeyer, 2000), further studies should examine the reported effects in a longitudinal setting.

One might argue that simple memory issues caused the observed effects: If the average member learns five facts before discussion but only remembers three, it could be that part of the drop-off in post-discussion declarative knowledge in the unshared condition is due to an inability to remember all ten cues. As the questionnaire on Tailorshop knowledge does not measure the ability to reproduce the exact paragraphs but knowledge of variable relations, variable features, and rules of thumb, we cannot employ

Tailorshop knowledge scores to determine which cues were remembered before and after the discussion. However, participants were allowed to take notes during learning and discussion and were allowed to use them during the simulation task. Thus, the effect of information overlap on actual task performance cannot be explained solely by individual memory effects.

A practical implication of the present study concerns the composition of work groups and teams. Teams that come together between intervals of individual task completion can benefit from a medium informational heterogeneity among group members. If group members are too heterogeneous in their knowledge, they should first exchange their knowledge and opinions on the matter to hand in order to achieve a larger overlap before dealing with the problem itself. On the other hand, a certain degree of differences in terms of expertise is likely to be fruitful for effective complex problem solving. Thus, group members do not need to share all relevant knowledge before decision making.

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References

Alferes, V. R., & Kenny, D. A. (in press). SPSS programs for the measurement of nonindependence in standard dyadic designs. *Behavior Research Methods.*

Badke-Schaub, P., & Buerschaper, C. (2001). Creativity and complex problem solving in the social context. In C. M. Allwood & M. Selart (Eds.), *Decision making: Social and creative dimensions* (pp. 177–196). Dordrecht: Kluwer Academic Publishers.

Badke-Schaub, P., & Strohschneider, S. (1998). Complex problem solving in the cultural context. *Le Travail Humain, 61*, 1–28.

Bales, R. F., & Strodtbeck, F. L. (1951). Phases in group problem-solving. *Journal of Abnormal and Social Psychology, 46*, 485–495.

Berry, D. C. (1984). Implicit and explicit knowledge in the control of complex systems. Unpublished doctoral dissertation, University of Oxford.

Berry, D. C. (1991). The role of action in implicit learning. *Quarterly Journal of Experimental Psychology, 43*, 881–906.

Berry, D. C., & Broadbent, D. E. (1995). Implicit learning in the control of complex systems. In P. A. Frensch & J. Funke (Eds.), *Complex problem solving: The European perspective* (pp. 131–150). Hillsdale, NJ: Lawrence Erlbaum.

Brodbeck, F., & Greitemeyer, T. (2000). A dynamic model of group performance: Considering the group members' capacity to learn. *Group Processes & Intergroup Relations, 3*(2), 159–182.

Buchner, A., Funke, J., & Berry, D. C. (1995). Negative correlations between control performance and verbalizable knowledge: Indicators for implicit learning in process control tasks? *Quarterly Journal of Experimental Psychology, 48A*, 166–187.

Cannon-Bowers, J., Oser, R., & Flanagan, D. (1992). Work teams in industry: A selected review and proposed framework. In R. W. Swezey & E. Salas (Eds.), *Teams: Their training and performance* (pp. 355–377). Norwood, NJ: Ablex.

Cooke, N. J., Salas, E., & Stout, R. (2000). Measuring team knowledge. *Human Factors, 42*, 151–173.

Dorfman, J., Shames, V. A., & Kihlstrom, J. F. (1996). Intuition, incubation, and insight: Implicit cognition in problem solving. In G. Underwood (Ed.), *Implicit cognition* (pp. 257–298). Oxford: Oxford University Press.

Dörner, D., Kreuzig, H. W., Reither, F., & Stäudel, T. (1983). *Lohhausen. Vom Umgang mit Komplexität* [Lohhausen: On dealing with uncertainty and complexity]. Bern: Huber.

Ellis, A., Hollenbeck, J., Ilgen, D., Porter, C., West, B., & Moon, H. (2003). Team learning: Collectively connecting the dots. *Journal of Applied Psychology, 88*(5), 821–835.

Endres, J., & Putz-Osterloh, W. (1994). Komplexes Problemlösen in Kleingruppen: Effekte des Vorwissens, der Gruppenstruktur und der Gruppeninteraktion [Complex problem solving in small groups: Effects of previous knowledge, of group structure, and of group interaction]. *Zeitschrift für Sozialpsychologie, 25*(1), 54–70.

Frensch, P. A., & Funke, J. (1995). Definitions, traditions, and a general framework for understanding complex problem solving. In P. A. Frensch & J. Funke (Eds.), *Complex problem solving: The European perspective* (pp. 4–25). Hillsdale, NJ: Lawrence Erlbaum.

Funke, J. (1992). *Wissen über dynamische Systeme: Erwerb, Repräsentation und Anwendung* [Knowledge on dynamic systems: Acquisition, representation, and use]. Berlin: Springer.

Funke, J. (2001a). Dynamic systems as tools for analysing human judgement. *Thinking and Reasoning, 7*(1), 69–89.

Funke, J. (2001b). Neue Verfahren zur Erfassung intelligenten Umgangs mit komplexen und dynamischen Anforderungen [New methods for registering intelligent dealing with complex and dynamic requirements]. In E. Stern & J. Guthke (Eds.), *Perspektiven der Intelligenzforschung* (pp. 89–109). Lengerich: Pabst Science Publishers.

Funke, J., & Frensch, P. A. (2007). Complex problem solving: The European perspective – 10 years after. In D. H. Jonassen (Ed.), *Learning to solve complex scientific problems* (pp. 25–47). New York: Lawrence Erlbaum.

Gruenfeld, D., Martorana, P., & Fan, E. (2000). What do groups learn from their worldliest members? Direct and indirect influence in dynamic teams. *Organizational Behavior and Human Decision Processes, 82*(1), 45–59.

Hausmann, R. G. (2005). Elaborative and critical dialog: Two potentially effective problem-solving and learning interactions. Unpublished doctoral dissertation, University of Pittsburgh, Department of Philosophy. Available from http://etd.library.pitt.edu/ETD/available/etd-08172005–144859/unrestricted/RGMHausmannETD2005.pdf

Heider, F. (1958). *The psychology of interpersonal relations.* New York: Wiley.

Hinsz, V., Tindale, R., & Vollrath, D. (1997). The emerging conceptualization of groups as information processors. *Psychological Bulletin, 121*, 43–64.

Jäger, A. O., Süß, H. M., & Beauducel, A. (1997). *Berliner Intelligenzstruktur-Test (BIS-Test)* [Berlin Intelligence Structure Test (BIS-Test)]. Göttingen: Hogrefe.

Kenny, D. A., Kashy, D. A., & Cook, W. L. (2006). *Dyadic data analysis.* New York: Guilford Press.

Kersting, M. (1999). *Diagnostik und Personalauswahl mit computergestützten Problemlöseszenarien? Zur Kriteriumsvalidität von Problemlöseszenarien und Intelligenztests* [Diagnostics and employee selection using computer-supported problem solving scenarios? On the criterion validity of problem solving scenarios and intelligence tests]. Göttingen: Hogrefe.

Kersting, M., & Süß, H. M. (1995). Kontentvalide Wissensdiagnostik und Problemlösen: Zur Entwicklung, testtheoretischen Begründung und empirischen Bewährung eines problemspezifischen Diagnoseverfahrens [Content valid knowledge diagnosis and problem solving: On the development, test-theoretical explanation, and empirical approval of a problem-specific diagnostic method]. *Zeitschrift für Pädagogische Psychologie, 9*(2), 83–93.

Klocke, U. (2004). *Folgen von Machtausübung und Einflussnahme für Wissenszuwachs und Effektivität in Kleingruppen* [The effects of the exercise of power and influence on knowledge increase and effectiveness in small groups]. Berlin: Dissertation.de.

Klocke, U. (2007). How to improve decision making in small groups: Effects of dissent and training interventions. *Small Group Research, 38*, 437–468.

Kluge, A. (2004). *Wissenserwerb für das Steuern komplexer Systeme* [Knowledge acquisition for the control of complex systems]. Lengerich: Pabst.

Kluge, A. (2008). Performance assessments with microworlds and their difficulty. *Applied Psychological Measurement, 2*(32), 156–180.

Kluwe, R. (2006). Informationsaufnahme und Informationsverarbeitung [Information acquisition and information processing]. In B. Zimolong & U. Konradt (Eds.), *Enzyklopädie der Psychologie: Wirtschafts-, Organisations- und Arbeitspsychologie* (Vol. 2: Ingenieurpsychologie, pp. 35–71). Göttingen: Hogrefe.

Kluwe, R., Haider, H., & Misiak, C. (1990). Learning by doing in the control of a complex system. In H. Mandl, E. Bennett, E. de Corte, & H. F. Friedrich (Eds.), *Learning and instruction* (pp. 197–218). Oxford: Pergamon Press.

Larson, J., Christensen, C., Franz, T., & Abbott, A. (1998). Diagnosing groups: The pooling, management, and impact of shared and unshared case information in team-based medical decision making. *Journal of Personality and Social Psychology, 75*, 93–108.

Laughlin, P., Bonner, B., & Miner, A. (2002). Groups perform better than the best individuals on Letters-to-Numbers problems. *Organizational Behavior and Human Decision Processes, 88*(2), 605–620.

Laughlin, P., Gonzalez, C., & Sommer, D. (2003). Quantity estimations by groups and individuals: Effects of known domain boundaries. *Group Dynamics: Theory, Research, and Practice, 7*(1), 55–63.

Levine, J., Resnick, L., & Higgins, E. (1993). Social foundations of cognition. *Annual Reviews in Psychology, 44*(1), 585–612.

Markowitsch, H. J. (1999). *Gedächtnisstörungen* [Memory disorders]. Stuttgart: Kohlhammer.

Nonaka, I., & Konno, N. (1998). The concept of 'ba': Building a foundation for knowledge creation. *California Management Review, 40*(3), 40–54.

Ohtsubo, Y. (2005). Should information be redundantly distributed among group members? Effective use of group memory in collaborative problem solving. *Journal of Applied Cognitive Psychology, 19*, 1219–1233.

Polanyi, M. (1958). *Personal knowledge.* London: Routledge & Kegan Paul.

Polanyi, M. (1966). *The tacit dimension.* Garden City, NY: Doubleday.

Powell, A., Piccoli, G., & Ives, B. (2004). Virtual teams: A review of current literature and directions for future research. *The DATA BASE for Advances in Information Systems, 35*(1), 6–36.

Preußler, W. (1998). Strukturwissen als Voraussetzung für die Steuerung komplexer dynamischer Systeme [Structural knowledge as a requirement for complex system control]. *Zeitschrift für Experimentelle Psychologie, 45*(3), 218–240.

Quesada, J., Kintsch, W., & Gomez, E. (2002). A computational theory of complex problem solving using latent semantic analysis. In W. D. Gray & C. D. Schunn (Eds.), *Proceedings of the 24th Annual Conference of the Cognitive Science Society Fairfax, VA* (pp. 750–755). Mahwah, NJ: Lawrence Erlbaum.

Rulke, D. L., & Galskiewicz, J. (2000). Distribution of knowledge, group network structure, and group performance. *Management Science, 46*(5), 612–625.

Scholl, W. (1996). Effective teamwork: a theoretical model and a test in the field. In E. Witte & J. H. Davis (Eds.), *Understanding group behavior* (Vol. 2: *Small group processes and interpersonal relations*, pp. 127–146). Mahwah, NJ: Lawrence Erlbaum.

Scholl, W. (1997). Gruppenarbeit: Die Kluft zwischen sozialpsychologischer Theoriebildung und organisationspsychologischer Anwendung [Group work: The gap between the construction of social-psychological theories and organizational practice]. *Gruppendynamik, 28*(4), 381–403.

Scholl, W. (2005). Grundprobleme der Teamarbeit und ihre Bewältigung: Ein Kausalmodell [Basic problems of group work and their solution: A causal model]. In M. Högl & H. G. Gemünden (Eds.), *Management von Teams* (3rd ed., pp. 33–66). Wiesbaden: Gabler.

Schuler, H., Frier, D., & Kaufmann, M. (1993). *Personalauswahl im europäischen Vergleich* [A European comparison of personnel selection techniques]. Göttingen: Hogrefe.

Stasser, G. (1992). Pooling of unshared information during group discussions. In S. Worchel, W. Wood, & J. A. Simpson (Eds.), *Group process and productivity* (pp. 48–67). Newbury Park, CA: Sage.

Stasser, G., & Stewart, D. (1992). Discovery of hidden profiles by decision-making groups: solving a problem versus making a judgement. *Journal of personality and social psychology, 63*(3), 426–434.

Stasser, G., Taylor, L., & Hanna, C. (1989). Information sampling in structured and unstructured discussions of three- and six-person groups. *Journal of personality and social psychology, 57*(1), 67–78.

Stasser, G., & Titus, W. (1985). Pooling of unshared information in group decision making: Biased information sampling during discussion. *Journal of Personality and Social Psychology, 48*, 1467–1478.

Stasser, G., & Titus, W. (1987). Effects of information load and percentage of shared information on the dissemination of unshared information during group discussion. *Journal of Personality and Social Psychology, 53*, 81–93.

Süß, H. M. (1996). *Intelligenz, Wissen und Problemlösen: Kognitive Voraussetzungen für erfolgreiches Handeln bei computersimulierten Problemen* [Test intelligence, knowledge, and problem solving: Cognitive requirements for successful performance on computer-simulated problems]. Göttingen: Hogrefe.

Süß, H. M., & Faulhaber, J. (1990). *Berliner Version des Szenarios Schneiderwerkstatt* [Berlin version of the tailorshop scenario]. Computer Software. Freie Universität, Fachbereich Erziehungs- und Unterrichtswissenschaften, FPS 'Intelligenz und Wissen'.

Tindale, R. S., & Sheffey, S. (2002). Shared information, cognitive load, and group memory. *Group Processes & Intergroup Relations, 5*(1), 5–18.

van Knippenberg, D., De Dreu, C. K. W., & Homan, A. C. (2004). Work group diversity and group performance: An integrative model and research agenda. *Journal of Applied Psychology, 89*(6), 1008–1022.
van Knippenberg, D., & Schippers, M. (2007). Work group diversity. *Annual Review of Psychology, 58*, 515–541.
Williams, K. Y., & O'Reilly, C. A. (1998). Demography and diversity in organizations: A review of 40 years of research. *Organizational Behavior, 20*, 77–140.
Wittmann, W. W., Süß, H. M., & Oberauer, K. (1996). Determinanten komplexen Problemlösens [Determinants of complex problem solving]. *Berichte des Lehrstuhls Psychologie II der Universität Mannheim, 9*, 1–25.

Biographical notes

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