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DO VIRTUAL GROUPS RECOGNIZE SITUATIONS IN WHICH IT IS ADVANTAGEOUS TO CREATE DIGITAL CONCEPT MAPS?

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Abstract. In the present experimental study, it was investigated whether virtual groups, depending on their situational circumstances, were able to decide in favor of the more suitable problem-solving procedure for their situation. The situational circumstances were to either have the possibility to create a "knowledge and information awareness" approach or not, that is, an approach that provides to the group members their collaborators' knowledge and information by means of digital concept maps. The study compared 20 triads with spatially distributed group members that were able to create a "knowledge and information awareness" approach with 20 triads collaborating without this possibility. Results showed, as expected, that the triads mostly chose the more suitable problem-solving procedure for their situation and that deciding in favor of the more suitable procedure resulted in both less time needed for solving the problems and less perceived coordination effort. However, triads that were able to create a "knowledge and information awareness" approach often did not finish their approach and could therefore not benefit from the full potential of this approach. The results are discussed.

1 Theoretical Background

1.1 The Benefits of Knowing What the Collaborators Know

Different fields of research show us the importance of knowing what the collaborators know in order to be able to communicate and collaborate effectively in group situations (Engelmann & Hesse, 2010). The research on audience design (e.g. Dehler-Zufferey, Bodemer, Buder & Hesse 2011) gives reason to believe that knowing what the collaborators know leads to changes of behavior such as writing longer texts about a topic when addressing novices (e.g., Dehler, Bodemer, & Buder, 2007). The knowledge imputing approach by Nickerson (1999) points out that knowing what the communication partner knows improves the communication by avoiding possible misunderstandings. The theory of transactive memory system (Wegner, 1986, 1995) states that group members need to know which member possesses knowledge about which topic in order as to access it through communication. An effective transactive memory system has shown to improve group performance (e.g. Liang, Moreland & Argote, 1995).

This knowledge about the collaborators' knowledge is, however, quite difficult to acquire: For example, groups need enough time to acquire it (e.g. Wegner, 1986) and many different mistakes may occur during the acquisition process (Nickerson, 1999). The acquisition of such knowledge is especially challenging for virtual groups, that is, in cases in which the spatially distributed members have to collaborate computer-supported; these groups have to struggle with reduced contextual information caused by the use of computers (cf. Kiesler, Siegel, & McGuire, 1984). The "knowledge and information awareness" (KIA) approach (e.g. Engelmann, Tergan, & Hesse, 2010; Engelmann & Hesse, 2010; Schreiber & Engelmann, 2010; Engelmann & Hesse, 2011) is a proven solution for these kinds of problems.

1.2 The KIA Approach and Coordination Theory

According to Engelmann and colleagues (e.g., Engelmann & Hesse, 2010), KIA is defined as being informed with regard to the collaborators' knowledge structures and underlying information. KIA is fostered by providing the group members with access to both their collaborators' knowledge structures and underlying information both visualized via digital concept maps. In the study these concept maps consisted of task-relevant labeled concepts as well as relations between those concepts which, as a whole, embodied both the knowledge structures and the information of the collaborators. Elements with additional information were linked to the concepts and could be opened in a small desktop window by mouse-clicking.

In several studies, this approach has been empirically proven to foster KIA acquisition of spatially distributed group members who collaborated computer-supported (e.g., Engelmann & Hesse, 2010; Schreiber & Hesse, 2010). Besides this, the KIA approach was also confirmed to improve computer-supported collaborative problem-solving: It enhanced group-performance in simulated virtual triads, meaning three persons sitting in the same room, able to speak with each other but not able to see each other because of partition walls (Engelmann et al., 2010). A follow-up study with real virtual groups, meaning groups with spatially distributed members, replicated these findings (Engelmann & Hesse, 2010). Evidence for this effect was also found with more complex tasks and different knowledge domain material (Schreiber & Engelmann, 2010).

One reason for the effectiveness of this approach is that it facilitates coordination. According to Malone and Crowston (1994), coordination is the management of dependencies between activities. Especially in the field of collaborative problem-solving and knowledge management, the management of producer-consumer relationships is very important. Producer-consumer relationships, as Malone and Crowston (1994) state, often lead to special kinds of dependencies such as 'prerequisite constraints' or 'transfer'. 'Prerequisite constraints' are activities that have to be finished before other activities can be started. For example, before person B is able to make a decision or solve a problem, person A has to provide the needed information. 'Transfer' takes place in between, when the producer communicates or 'transfers' information to the consumer. The coordination or management of these dependencies in a group problem-solving setting entails effort or costs, such as time costs for prerequisite constraints or the need to correct mistakes that appeared in the information transfer process. If the coordination costs are low, the coordination process is effectively.

It is expected that the KIA approach improves coordination: In the process of group knowledge building as a requirement for group problem-solving, the KIA approach provides the opportunity to make parts of the individual knowledge of the group members available before the individual knowledge building process is completed. Parts of the individual knowledge as a product can be used by others before the entire product is completed. This should lead to a time advantage compared to groups whose members cannot see parts of others individual knowledge before it is completed. Moreover, having the possibility to see the knowledge of the collaborators makes it possible to use this knowledge without the need to ask for it, or in return, to communicate it. This should lead to both fewer mistakes and less time needed for completing collaborative tasks. As a result of such process costs reductions, the collaborative problem-solving of groups provided with the KIA approach should be more effective and efficient.

1.3 Bringing the KIA Approach into Practice

Prior studies of Engelmann and colleagues (e.g. Engelmann & Hesse, 2010) were highly structured and the utilization of the KIA approach was predetermined because the group members worked with maps that were created by an expert (instead of by the group members themselves). These expert maps contained the complete content needed to solve the problems. Individual and collaborative work phases were separated from each other and offered enough time to accomplish each task. This design differs from real application fields in which group members need to externalize their individual knowledge by themselves. Moreover, groups need to decide in favor of a suitable, coordinated problem-solving procedure, depending on the situational circumstances (West, 1996). They also need to adapt their activities to the situational or environmental circumstances as a requirement for a coordinated procedure (Salas, Sims & Burke, 2005). Such environmental circumstances are, for example, technical characteristics and affordances. In the present study, the situational circumstances were to either have the possibility to create a KIA approach or not. This leads to our research question: Depending on whether the groups in an unstructured situation have the possibility to create a KIA approach or not, do they opt for a procedure that is suited to effective, computer-supported collaborative problem-solving?

2 Experimental Study

The present study compared a control condition with an experimental condition. The groups in the experimental condition had the possibility to create a KIA approach, meaning that each group member could first visualize his/her own knowledge and information by means of a digital concept map which afterwards was provided to the other group members during a collaborative problem-solving phase. In contrast, the groups in the control condition did not have this possibility. These group members could create individual concept maps, but these maps would not be shared with the other group members during the collaborative problem-solving phase.

We expected that groups, according to situational circumstances, would decide in favor of a suitable problem-solving procedure: The suitable procedure for the experimental groups would be that all group members, after having started to create their own concept map, continue with their individual maps before starting to collaborate, that is, to continue finishing the representation of their own knowledge and information. This is because the completed individual maps provided to the collaborators would function as a KIA approach that improves collaborative problem-solving. In contrast, the suitable procedure for the control groups would be that the group members start directly with collaboration because they cannot see the completed partner maps and, therefore, cannot create a KIA approach. Thus, we propose the following hypotheses:

- *Hypothesis 1:* Groups, depending on situational circumstances, that is, depending on the possibility to create a KIA approach, choose the more suitable problem-solving procedure for their situation, which means that groups in the experimental condition decide more often to continue first with their individual maps while groups in the control condition decide more often to start directly with collaboration.

- *Hypothesis 2:* Groups in the experimental condition that first continue with their individual maps and groups in the control condition that start directly with collaboration need less time for collaboration than those groups in the experimental condition that do not continue with their individual maps and those in the control condition that do not start directly with collaboration.
- *Hypothesis 3:* Groups in the experimental condition that first continue with their individual maps and groups in the control condition that start directly with collaboration perceive less coordination effort than those groups in the experimental condition that do not continue with their individual maps and those in the control condition that do not start directly with collaboration.

Prior studies have confirmed that a completed KIA approach, that is, having access to the concept maps of the collaborators, visualizing their complete knowledge and information, improves collaborative problem-solving. Therefore, we hypothesized the following:

- *Hypothesis 4:* Groups in the experimental condition that first continue with their individual maps outperform groups in the experimental condition that directly start collaboration and groups in the control condition that either continue or do not continue with their individual maps.

3 Method

3.1 Participants

Participants were 120 university students (94 female, 26 male) from different fields of study with an average age of 23.8 years (SD = 3.3). Both conditions consisted of 20 groups with 3 participants randomly assigned to one of the two conditions. They were rewarded with either payment or course credits. The group composition regarding gender was controlled: In each condition were three groups with one woman, seven groups with two women, and ten groups with only women. The degree of acquaintance between the group members was also controlled: Participants indicated in a questionnaire whether they knew none, one, or both of the collaborators. There was no significant difference between the conditions regarding the degree of acquaintance ($F < 1$).

3.2 Materials and Procedure

The members of every triad worked spatially distributed in different rooms equipped with a desk and a computer.

At the beginning of the empirical study, the participants filled out an online control measure questionnaire consisting of 16 multiple choice items (e.g. items regarding experience with computers, mapping techniques, and group work) designed as five-point rating scales ranging from complete agreement to no agreement. Then they were trained in how to use CmapTools (http://cmap.ihmc.us/), a digital concept mapping software.

After ensuring that all participants could handle the tool, the main phase of the study began. Group members read the instructions informing them about their role in the study: They were asked to imagine that each one of them was a different expert who had to collaborate with two other experts in order to protect a spruce forest. For this purpose two problems had to be solved: First, the group had to decide and justify which pesticide they would use to protect the spruce forest. Second, they had to decide and justify which fertilizer they would use.

The domain material used was given as a text document file (i.e. a Word document), which was presented as being a group member’s own notes. It consisted of several concepts (e.g., spruce), relations between concepts (e.g., a spruce needs less nitrate) and background information (e.g., more detailed and verbal explanations of the concepts) that were evenly distributed among the three group members: Each member had several concepts, relations, and background information that were unshared, shared with one collaborator, or shared with both collaborators.

The members then had nine minutes to individually create a concept map visualizing their individual knowledge and its underlying information. However, in order to increase coordination effort in the subsequent phase, the time provided was too short for finishing one’s own individual map. The groups were then informed that the problem-solving phase would start: Now they could decide whether they wanted to finish their individual maps first or to start directly to collaborate. The groups had 50 minutes to solve the two problems, which could only be solved by compiling the knowledge and information of every single member. To find the solutions, they had to create a common concept map in their shared working window. In this phase, they could communicate with each other via Skype. The control condition did not have the possibility to create a KIA approach; that is, each member could only see his/her own individual map as well as the common concept map (see Figure 1). It was expected that seeing only one's own unfinished map would have a low affordance to finish it because no one else would know that it was still unfinished. The experimental condition did have the possibility to create a KIA approach: Members of the experimental condition were not only able to see their own individual maps but also the individual maps of their collaborators. In addition, they also had access to the shared working window for creating the common concept map (see Figure 2). It was expected that seeing the three unfinished individual maps would have high affordance to complete them (cf. Suthers, 2006). Completed individual maps result in a completed KIA approach for collaboration.

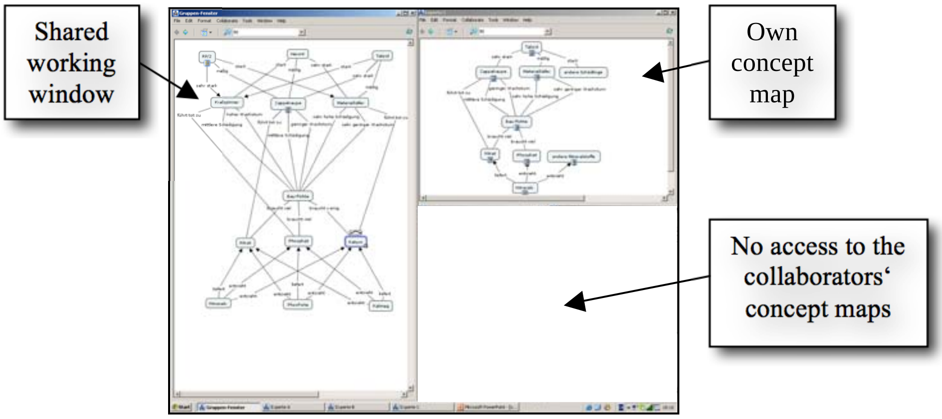

Figure 1. Screen of the control condition in the collaborative problem-solving phase

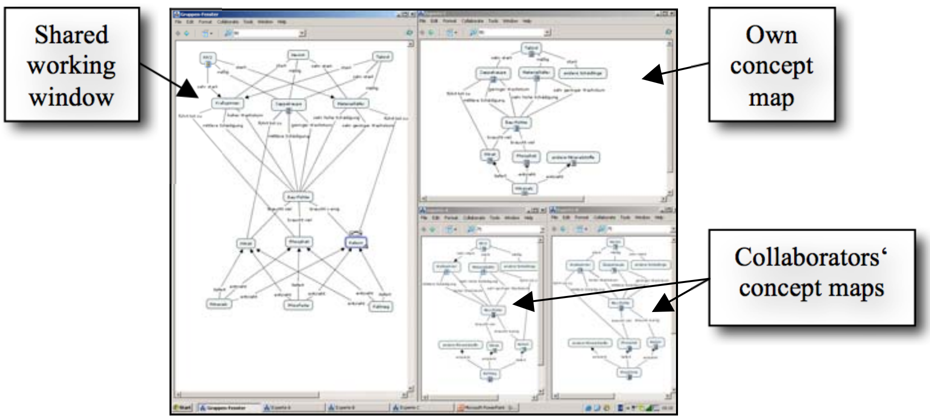

Figure 2. Screen of the experimental condition in the collaborative problem-solving phase

In this phase, log files of creating the common maps (by CmapTools) as well as video and audio files (by Camtasia) were recorded.

Following this phase, each group member worked again individually: First, they answered an online test measuring the amount of acquired KIA by means of 36 multiple-choice test items (example-item: "Please mark which expert(s) had information about the relation between RP/2 and fidget-grub - Expert A, B, or C?"). Second, each group member completed a questionnaire for evaluating the study and aspects of collaboration, coordination, and problem-solving. The items were assessed by five-point rating scales ranging from 1 point for no agreement and 5 points for complete agreement. The questionnaire contained 42 items in the control condition. There were 52 items in the experimental condition due to some additional items referring to the usefulness of seeing the collaborators' maps containing their knowledge structure and information. Participants neither had time limits nor access to the experimental environment while filling in the KIA test and the questionnaire.

In comparison to previous studies by Engelmann and colleagues (Engelmann & Hesse, 2010, 2011), the main differences in the procedure was that the participants had to create their individual concept maps by themselves. Further, the short time frame for creating the individual map and the freedom of choice in how to proceed at the beginning of the problem-solving phase forced the group members to more coordination effort.

4 Results and Discussion

All analyses presented here are based on group level data because the individuals in a group were not independent of each other. In this paper, we will report partial eta-squared values (η_p^2) as a descriptive index of strength of the association between the experimental factor and a dependent variable (Cohen, 1973). Such a value is defined as “the proportion of total variance attributable to the factor”, excluding other factors’ impact (Pierce, Block, & Aguinis, 2004, p. 918).

With regard to the control measure items (e.g., experience in group work), a factor analysis with Varimax rotation was conducted resulting in two interpretable factors, namely, “experience with computers” and “preference for using different information resources”. For each of these factors a univariate ANOVA was performed showing that there were no significant differences between the two conditions (*F*s < 1). Therefore, the inclusion of a covariate was not necessary.

In accordance with *Hypothesis 1* (postulating that the triads of the conditions choose the more suitable problem-solving procedure, that is, that the experimental groups decide more often to continue with their individual maps first before starting to collaborate, while the control groups decide more often to start directly with collaboration), more experimental groups decided to finish the individual maps first (i.e., 12 of the 20 groups) compared to the control groups (4 of 20 groups), while most control groups started directly to collaborate (i.e., 16 of the 20 groups) (Pearson-χ^2 (1, N = 40) = 6.7, p = .01). However, in the experimental condition, only 12 of 20 groups opted for the more suitable procedure. One reason for this proportion being lower than expected could be that groups did not recognize the advantage of completed individual maps that result in a completed KIA approach.

In line with *Hypothesis 2* (postulating that groups that choose the more suitable problem-solving procedure for their situation need less time for solving the problems), the ANOVA resulted in a significant interaction indicating that continuing with the individual maps was only helpful for solving the first problem for experimental groups, while continuing with the individual maps increased the collaboration time needed for the control groups ($F(1,36) = 5.17$; MSE = 192167.2; $p < .05$; $\eta_p^2 = .13$). The same kind of interaction was found for solving the second problem ($F(1,36) = 3.83$; MSE = 259092.1; $p = .058$; $\eta_p^2 = .10$). The means are provided in Table 1. These interactions were expected because the experimental groups that continued with their individual maps could benefit from the completed KIA approach that reduces the time needed for problem-solving. Due to the fact that the control groups could not benefit from the finished individual maps, because in the problem-solving phase, the members were not provided with the collaborators’ individual maps, for them the best procedure was, as expected, to start directly with the collaboration.

	Experimental groups		Control groups	
	Problem 1	Problem 2	Problem 1	Problem 2
Continued with individual maps	**26:40** (06:35)	**28:03** (09:85)	32:58 (09:23)	37:30 (06:22)
Started directly with collaboration	30:23 (07:14)	32:47 (08:05)	**24:41** (07:21)	**30:15** (07:49)

Table 1: Means (and standard deviations) of the needed time for solving problem 1 and 2

In accordance with *Hypothesis 3* (postulating that groups that opt for the more suitable problem-solving procedure perceive less coordination effort), the ANOVA resulted again in a significant interaction showing that experimental groups that continued with their individual maps and control groups that started directly to collaborate perceived less coordination effort than groups that did not opt for their most suitable procedure $F(1,36) = 4.80$; MSE = 0.90; $p < .05$; $\eta_p^2 = .12$, see also Table 2). Coordination effort was a factor that resulted from a factor analysis including items of the questionnaire that was answered after the problem-solving phase.

	Experimental groups	Control groups
Continued with individual maps	**-0.07** (1.50)	0.38 (1.50)
Started directly with collaboration	0.68 (1.01)	**-0.38** (0.65)

Table 2: Means (and standard deviations) of the perceived coordination effort

However, in contrast to *Hypothesis 4*, we did not find that experimental groups that continued with the individual maps outperformed the other three conditions with regard to collaborative problem-solving performance (All *F*s > 1, see also Table 3). This was unexpected because finished individual concept maps, visualizing the group members' knowledge and information, that are provided to their collaborators, result in a completed KIA approach that was proven to foster collaborative problem-solving (cf. Engelmann & Hesse, 2010).

	Experimental groups	Control groups
Continued with individual maps	**4.3** (2.2)	4.5 (2.1)
Started directly with collaboration	4.4 (2.7)	4.4 (2.6)

Table 3: Means (and standard deviations) of the collaborative problem-solving performance

Additional analyses gave an explanation for this unexpected finding: As expected, we found indeed that experimental groups that continued with their individual maps (E_con) included more correct nodes and correct relations in their individual maps, compared to experimental groups that did not continue with their individual maps, that is, that collaborated directly (E_coll) (regarding nodes: M_{E_con} = 23.00; SD_{E_con} = 4.90; M_{E_coll} = 17.75; SD_{E_coll} = 3.41; $F(1,18) = 6.89$; $MSE = 19.19$; $p < .05$; $\eta_p^2 = .28$; regarding relations: M_{E_con} = 28.33; SD_{E_con} = 7.55; M_{E_coll} = 18.88; SD_{E_coll} = 5.41; $F(1,18) = 9.30$; $MSE = 46.20$; $p < .01$; $\eta_p^2 = .34$). However, the continued maps of the experimental groups contained on average only 77% of all correct nodes and only 63% of all correct relations. That is, the experimental groups that continued with their individual maps did not finish their individual maps and therefore could not profit from a completed KIA approach.

In addition, we found that the experimental groups that continued with their individual maps did not improve the problem-solving potential of their individual maps: that is, they did not increase the problem-relevant aspects of their individual maps, compared to experimental groups that did not continued with their individual maps (M_{E_con}= 1.17; SD_{E_con} = 0.94; M_{E_coll} = 0.63; SD_{E_coll} = 0.74; $F(1,18) = 1.87$; $MSE = 0.75$; $p > .05$). This is also an explanation for the missing effect, that is, an explanation for the result that the experimental groups that continued with the individual maps did not outperform the other three conditions with regard to collaborative problem-solving performance.

A further explanation for this missing effect on the collaborative problem-solving performance is that the experimental groups that continued with their individual maps did not acquire more KIA compared to experimental groups who started directly to collaborate (M_{E_con} = 14.00; SD_{E_con} = 2.02; M_{E_coll} = 13.02; SD_{E_coll} = 2.14; $F(1,18) = 1.07$; $MSE = 4.26$; $p > .05$).

5 Summary and Implications

In the present experimental study, it was investigated whether virtual groups, depending on their situational circumstances, were able to choose the more suitable problem-solving procedure for their situation. The situational circumstances were to either have with the possibility to create a KIA approach or not, that is, an approach that provides to the group members their collaborators' knowledge and information by means of individual digital concept maps. In more detail, after an individual phase too short for creating and finishing one's own individual concept map representing one's own knowledge and information, a problem-solving phase started. In this phase, all groups could decide how to proceed, that is, to first finish the individual concept maps or to start directly with collaboration. In the problem-solving phase, each member of the control groups could only see their own unfinished concept map, while each member of the experimental groups had also access to his/her collaborators' maps; that is, they were provided with the possibility to create a KIA approach.

The study compared 20 triads with spatially distributed group members that were able to create a KIA approach (experimental condition) with 20 triads collaborating without this possibility (control condition).

Results showed, as expected, that the triads opted predominantly for the more suitable problem-solving procedure for their situation: The experimental groups that could create a KIA approach decided mostly to first continue with their individual concept maps visualizing their own knowledge and information. These maps were provided to their collaborators and could be used as a KIA approach. In contrast, the control groups, which were not able to create a KIA approach, decided mostly to start directly with collaboration instead of continuing with their individual maps that could not be provided to the collaborators.

As expected, opting for the more suitable procedure resulted in both less time needed for solving the problems and less perceived coordination effort. Therefore, this study demonstrated that also in unstructured situations having access to the collaborators' knowledge structures and underlying information (or to parts of these structures) helps to reduce the needed collaboration time and the perceived coordination effort.

However, groups having the possibility to create a KIA approach often did not continue to finish their individual maps and – if they did – they discontinued the task too early; that is, they did not finish the individual maps. As a result, they could not profit from a completed KIA approach that would improve their collaborative problem-solving performance. A possible explanation could be that they did not recognize the potential of a completed KIA approach and did not expect that the needed time for finishing the maps is time that reduced the collaboration time.

Currently, we are planning a follow-up study with a focus on motivating group members to complete their individual maps so that they could benefit from a completed KIA approach that is expected to increase their group performance.

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