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CONCEPT MAPS USED AS A "KNOWLEDGE AND INFORMATION AWARENESS" TOOL FOR SUPPORTING COLLABORATIVE PROBLEM SOLVING IN DISTRIBUTED GROUPS

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Abstract. In today's information society, computer-supported collaborative learning (CSCL) has become increasingly important. However, there are still problems regarding CSCL, especially interaction problems within groups. This study is an investigation of whether a specific kind of awareness tool, namely a tool for making the collaborators aware of relevant domain knowledge and the information underlying this knowledge, is an efficient means to foster computer-supported collaborative problem solving in the context of resource-based learning. In the study presented, an experimental condition, in which the group members of a triad had a "knowledge and information awareness" tool (KIA-Tool), is compared to a control condition, in which the group members did not have it. First results showed that, despite additional information the participants in the experimental condition had to deal with, the KIA-Tool leads to higher performance.

1 Introduction

In today's information society, Network-based collaborative problem solving by spatially distributed group members is becoming increasingly important. However, problems in collaboration arise because of a variety of factors, among them the lack of competency in structuring collaboration in shared virtual work spaces, the lack of awareness regarding the availability and activities of the group members, and a lack of awareness about their knowledge of subject matter and their mental representation of a particular problem situation. Because of the complexity of influencing factors in Web-based scenarios, individuals often suffer from cognitive overload as well as from conceptual and navigational disorientation (Bleakley & Carrigan, 1994). In order to collaborate effectively, group members often need to organize and represent subject-matter knowledge as well as task-relevant information resources associated with it. Research in computer-supported collaborative learning (CSCL) has yielded valuable knowledge regarding how to foster this style of learning. Two strands of research address problems relative to CSCL. On the one hand, there are approaches that support CSCL by explicit methods like scripting (e.g., Kollar, Fischer, & Slotta, 2005). On the other hand, there are approaches that seek to support CSCL by using implicit methods focused on enhancing different kinds of group awareness (e.g., Gross, Stary, & Totter, 2005). Awareness according to Endsley (1995) is concerned with "knowing what's going on" in a group situation. Until now, research on fostering awareness has focused on social and behavioral aspects, i.e., knowledge about current availability and activities of the group members (e.g., Carroll, Neale, Isenhour, Rosson, & McCrickard, 2003). However, the authors of this paper suggest that social and activity awareness may not be enough to support effective collaboration. Knowledge is needed about the mental representations regarding the task domain of each of the group members, the concepts and information resources they use and share, as well as the knowledge gaps that are responsible for misunderstandings, ineffective shared knowledge construction, and deficient problem solving.

Graphical external representations are suggested to foster externalized cognition (e.g., Cox, 1999) and enhance the cognitive processes of managing knowledge and information in resource-based learning and problem solving environments. Knowledge and information visualizations have been shown to be effective for enhancing the cognitive processes of retrieving knowledge and task-relevant information (Tergan & Keller, 2005). Particularly, digital concept maps seem to have a potential as cognitive tools that may enhance individual and group-related cognitive processes in resource-based learning and problem solving (Tergan, 2005; Tergan, Keller, & Burkhard, in press). This paper ties in with the research endeavors of fostering knowledge and information awareness as a means for making the collaboration of spatially distributed group members more effective. A "knowledge and information awareness" tool (KIA-Tool) has been invented to make the knowledge of the collaborators about the concepts that have been used and the available information resources visible, and to support shared knowledge construction and collaborative problem solving. An empirical study investigating the potential of the KIA-Tool for supporting CSCL and its results are presented and discussed. The paper ends with a conclusion.

2 Problems of Computer-Supported Collaborative Learning

Computer supported collaborative learning and meaning making becomes increasingly important when learners have to construct a shared knowledge basis in order to cooperatively solve problems by using the Internet as a communication medium. According to Koschmann (2002) CSCL could be characterized as "practices of meaning-making in the context of joint activity, and the ways in which these practices are mediated through designed artifacts" (p. 18). Following this often cited definition, there are two important features that characterize CSCL: First, the collaboration aspect implies that a group, not only an individual, is involved. Stahl, Koschmann, and Suthers (2006) explain that this group learning "is not merely accomplished interactionally, but is actually constituted of the interactions between participants". This statement points out that in such situations the interaction between the group members is essential for group efficiency. Second, Koschmann's definition highlights the aspect of mediation through designed artifacts. This aspect refers to the computer support of the group interaction, i.e., the technology should be designed to mediate and encourage social acts that lead to efficient group work.

Results of empirical research suggest that learners in CSCL scenarios may provide more complete reports, may make decisions with higher quality, and may be better in idea generation (Fjermestad, 2004). However, research results also show that efficient computer-supported collaboration is not easy to achieve (Dewiyanti, Brand-Gruwel, & Jochems, 2005; Salomon, 1992). According to Janssen, Erkens, Jaspers, and Broeken (2005) groups who are learning collaboratively with computer support often have communication and interaction problems. They may perceive their discussion as confused (Thompson & Coovert, 2003), they may need more time to arrive at a consensus and for making decisions (Fjermestad, 2004), and they may need more time for solving tasks (Baltes, Dickson, Sherman, Bauer, & LaGanke, 2002). Following, for example, Carroll et al. (2003), in CSCL the group task is often not perceived as a group task; i.e., the group members work individually instead of collaboratively and coordination is missing. In addition, the individual group members often do not trust in the fact that the others are doing their part of the work. Additionally, the group members often do not perceive changes in the situation, the task, or the group.

CSCL research aims at studying the process of collaboration as well as the effectiveness of measures and tools for fostering collaboration and cooperation in computer-based learning and problem solving scenarios. The focus of empirical research in this area is generally on the study of methods and tools for scripting the communication process. Other research endeavors focus on methods and tools for fostering coherence and effectiveness of group processing by enhancing awareness with respect to group processes. As outlined in the introductory section, processes and effectiveness of cognitive awareness of the individual and the shared knowledge of the group members, as well as the information resources that are required for learning and problem solving, have not yet been studied.

3 Knowledge and Information Awareness to Enhance Computer-Supported Collaborative Learning

In the literature, there is no consensus about how the term awareness is described and defined. Following Christiansen and Maglaughlin (2003), there are 41 types of awareness. However, other authors try to differentiate awareness according to several dimensions. Carroll et al. (2003) for example, differentiate different types of awareness on the working processes level. While social awareness is defined as awareness regarding who is currently available for collaboration, action awareness additionally provides information regarding who is doing what at the moment as well as what happens currently. This last type of awareness refers to feedback on single occurrences. However, Carroll et al. (2003) point out the importance of activity awareness for computer-supported collaborative scenarios. They defined activity awareness as awareness regarding not only the information on who is currently available and who is doing what at the moment, but also awareness regarding the relevance of an activity with regard to the goal of the group.

However up to now, Carroll and his colleagues have not conducted controlled empirical studies to provide evidence for the efficiency of activity awareness.

In most papers, the meaning of awareness refers to both social awareness, in the sense of who belongs to the group and who is available, and action awareness, in the sense of who is doing or who did what. In collaborative problem solving when group members construct different individual knowledge representations based on different information resources and lack knowledge because of lacking information, social and activity awareness must be supplemented with “knowledge and information awareness”. A KIA-Tool might be used to enhance computer-supported collaborative learning by visualizing individual and shared knowledge as well as other related information. Such a tool might make individual group members aware of the knowledge of the other group members regarding the task domain as well as the information underlying that knowledge. Visualizations should externalize the knowledge structures and display the related information of the collaboration partners to support external cognition about the status of shared knowledge construction and the processes of knowledge communication.

Concept maps, developed by Joseph D. Novak (e.g., Novak & Gowin, 1984), are a type of knowledge visualization for representing the knowledge of a learner by means of nodes displaying concepts and labeled links between the nodes representing the relations between the concepts. While traditional concept maps were created by using paper and pencil, computer-based concept mapping tools allow for the creation of digital concept maps. An example is CmapTools developed by the Florida Institute of Human Machine and Cognition in Pensacola, FL (USA) (see, http://cmap.ihmc.us/). Traditional concept maps have been criticized for some shortcomings in representing knowledge. For example, they only visualize abstract concept knowledge leaving the content knowledge behind the concepts (e.g., examples and images) unconsidered (e.g., Tergan et al., in press). By contrast, advanced digital concept mapping tools allow the representation of content knowledge as well as hyper-linking a concept with additional information regarding the concept. When using a KIA-Tool users are not only able to check visually which concept is based on an information resource, but also can access information relevant for an explanation of a concept and its relation to other concepts. It is suggested that being aware of one’s own knowledge and the knowledge of others as well as the information resources linked to a concept may help cooperative learners and problem solvers in shared knowledge-construction and problem-solving tasks. CmapTools as a digital concept mapping tool provides facilities suited to the use of digital concept maps as KIA-Tools.

It is assumed that a KIA-Tool is helpful in a computer-supported collaborative learning scenario, because it could be expected that such a tool would have a positive impact on interaction, especially on the processes and the effectiveness of communication, coordination, and collaborative problem solving. On the one hand, following Clark and Brennan (1993) shared understanding in communication is crucial for learners working in groups. Making visual representations of the knowledge structures and the underlying information of each group member available to the group should facilitate shared understanding and knowledge construction. By referencing to the external representations, the group members are made aware of the status of individual knowledge representations. On the other hand, exchange of unshared information is very important (e.g., Stasser, Vaughan, & Stewart, 2000). It is shown that in CSCL information that is shared by all members is often mentioned in group discussion, while unshared information that is known by only one group member is often not mentioned. By comparing the external representations of the knowledge structures of the collaborators, group members can easily recognize which information is shared and which is not. This should have a positive effect on group coordination. In addition, it is assumed that the capability to view the knowledge of the others in the group provides a kind of affordance to make use of these representations (Suthers, 2005). The study outlined in the following passage tested these assumptions.

4 Experiment

This experiment investigated whether a tool for supporting awareness regarding the knowledge and information of the collaborators (KIA-Tool) leads to more efficient collaboration (in the sense of coordination and communication) of a group, and as a result, to more efficient problem solving compared to a condition with groups that did not use a KIA-Tool.

4.1 Method

4.1.1 Participants

Participants were 90 students (58 female, 32 male) of the University of Tuebingen, Germany. Average age was 24.47 (SD = 3.83). The students were randomly assigned to the experimental condition or to the control condition. Each group consisted of three participants, resulting in 15 control groups and 15 experimental groups.

4.1.2 Materials and Procedure

The participants worked in groups of three students in a room that was divided by partition walls into three separate sections. Each of the sections was equipped with a desk and a computer. The participants could not see each other, but could speak with each other. They were required to work in a spatially distributed, synchronous fashion with net-based, shared and unshared tools. The experimental environment used in this study provided information elements that are necessary to care for a fictitious kind of spruce forest. These information elements consisted of 13 concepts, 30 relations between these concepts, and 13 background resources (in parts divisible in sub-elements) and were evenly distributed among the three group members. Each participant had several unshared items, several items that were shared with one group member, and others that were shared with both group members.

The experimental environment consisted of two different software components. The first was an information space that contained the different information units the group members needed for solving the problems. This information space was based on Bebop, a Zope3-based groupware that was developed by Oestermeier, Kurbad, Knobloch, and Armbruster of the Institute of Knowledge Media in Tuebingen (Germany) (see, http://svn.iwm-kmrc.de/). The other was CmapTools (see section 3).

At the start of the study, the participants took a pencil-paper diagnostic test to measure several control variables including their experience with computers, mapping techniques, and group working skills. Afterwards, they received an introduction and practice using CmapTools. After ensuring that all participants could use CmapTools without problems, they started with individual phase 1 of the experiment. At the outset of this phase, participants were told that they are experts who have to protect a spruce forest and that they first have to refresh their domain expertise, before they start to collaborate and to find a common solution for the problems. During this phase, which lasted 23 minutes, the group members worked separately, accessing the information elements in their Bebop window and structuring their information and knowledge in their own working window (see Figure 1).

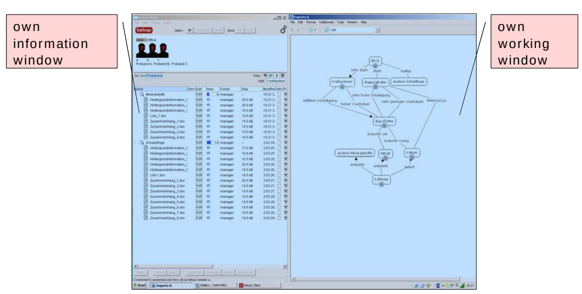

Figure 1. Individual phase 1.

In the individual phase 2, each participant of the control group had 5 minutes to examine his/her own map (see Figure 2, left side). Each participant of the experimental group, however, had 5 minutes to view his/her own map as well as the maps of his/her collaborators (see Figure 2, right side). After this activity, all participants had to fill out a questionnaire used as a manipulation check. This questionnaire contained 15 multiple choice items that measured the amount of knowledge the participants acquired from the maps.

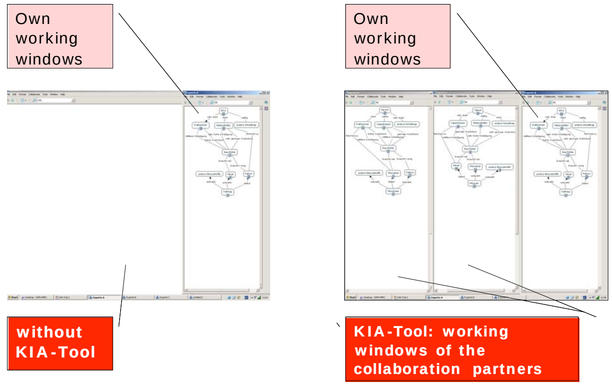

Figure 2. Individual phase 2 (left: control group; right: experimental group).

Subsequently, the three group members had to collaborate to solve two problems, i.e., which pesticide and which fertilizer they would use to protect and to cultivate the spruce forest. To solve these problems the participants needed to compile the knowledge and information they had structured and visualized in the individual phase 1 in the form of a digital concept map. To do this, they used a shared working window to create a common digital concept map containing all the knowledge and information they acquired in the individual phase. They had 40 minutes for collaboration. While collaborating they could speak with each other. They were told that they were using a kind of hands-free speaking system. In the control condition, the participants could only see their own working window and the shared working window (see Figure 3, left side). In the experimental condition, the participants also saw the individual maps of their collaborators, i.e., they were also aware of the knowledge and information their collaborators had (see Figure 3, right side). The individuals' interactions through the software and the audio data were recorded.

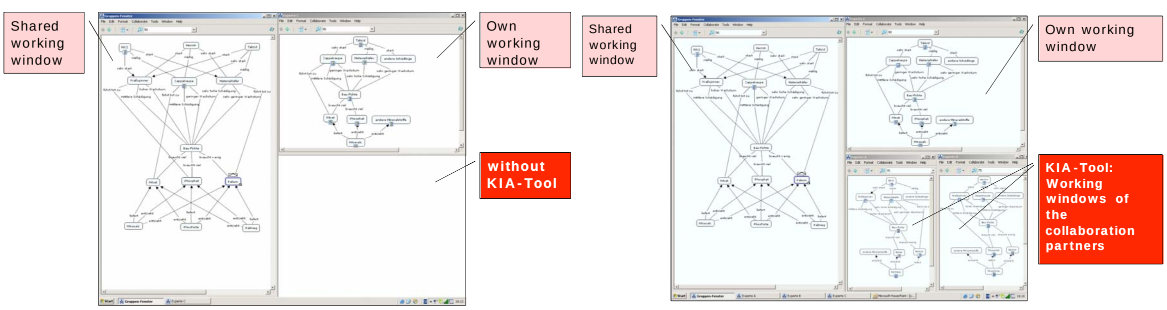

Figure 3. Individual phase 2 (left: control group; right: experimental group).

After this collaborative phase, the participants received another test containing 30 items to measure the knowledge they acquired regarding taking care of the spruce forest. In this test phase, the experimental environment was no longer available. There were no time limits on this test. At the end of the study, participants had to fill out a questionnaire asking for difficulties regarding communication and collaboration, the use of CmapTools, and how helpful the KIA-Tool was.

4.1.3 Design and Dependent Measures

The experimental analysis was based on a comparison of the control condition and the experimental conditions. In the experimental conditions, the participants were provided with a KIA-Tool, that is, they could see the individual concept maps of their collaboration partners and therefore were aware of the knowledge and information their collaborators had. In the control condition, the participants could not use a KIA-Tool.

With regard to the dependent measures, the distinction was made between product-related measures and process-related measures. The product-related measures could be divided into three types:

- First, the domain knowledge measured with 30 multiple-choice test items: Several sub-variables could be differentiated, for example, knowledge regarding relations and contents underlying a concept as well as knowledge pertaining to whether it is unshared, shared with one other member, or shared with both members.
- Second, the quality of the common concept map that the group created in the collaboration phase: Several description variables are differentiated, for example the number of correct nodes and relations, and the number of annotations.
- Third, the quality of the group answers to the two problem-solving tasks.

Regarding the process-related measures, the communication and collaboration aspects were of interest. In the collaboration phase, the development of the group map was recorded in a log file and the verbal communications were recorded in an audio file for later analysis. In addition, some subjective items in a questionnaire were captured. Although data analysis is still in progress, initial results are reported in the next section.

4.2 Results and Discussion

In all analyses of variance reported in this paper, the control measure item "experience on creating computer-based graphics" was used as a covariate. The reason is that with regard to this item, a significant difference existed between the control condition and the experimental condition, with a higher value in the sense of more experience in the control condition. Additionally, this item is strongly associated with dependent measures. With regard to other control items, there were no significant differences between the control and the experimental condition. All analyses presented here are based on group level, that is, the group values are calculated as means of the values of the individuals of a group. Analysis on the group level was necessary, due to the fact that the individuals in a group were not independent of each other.

The first analysis determined whether the KIA-Tool was used by the participants. For this purpose, some questionnaire items were analyzed that consisted of five-point rating scales with the number one for "no agreement", the number three for "partial agreement" and the number five for "complete agreement": The experimental groups agreed on average that it was helpful to have an overview of the maps of the collaborators ($M = 4.27$; $SD = 0.75$) and that seeing the maps of the others was useful ($M = 3.58$; $SD = 0.58$).

The second analysis explored whether the use of the KIA-Tool had an effect on the dependent measures: The questionnaire afterwards showed that the study was more stressful for participants in the control condition ($M_C = 3.2$; $M_E = 2.7$; $F(1,27) = 4.66$; $MSE = 0.28$; $p < .05$), although the experimental condition had more problems regarding the use of the different windows on the desktop ($M_C = 1.8$; $M_E = 2.2$; $F(1,27) = 6.25$; $MSE = 0.25$; $p < .05$), compared to the control groups. This last result was not unexpected, due to the fact that in the experimental condition the participants had to work with two more windows than the control condition. The result before showed that the cognitive load in the control condition was higher than in the experimental condition.

In addition, in the experimental condition the participants stated that the collaboration with each other led to a better overview regarding the relations of the domain compared to the control groups ($M_C = 4.0$; $M_E = 4.3$; $F(1,27) = 5.89$; $MSE = 0.22$; $p < .05$). This could be confirmed by the analysis of the domain knowledge measures: The analysis revealed better performance for the experimental groups regarding the knowledge on domain relations compared to the control groups ($M_C = 3.4$; $M_E = 3.7$; $F(1,27) = 3.43$; $MSE = 0.21$; $p = .075$). Regarding the domain knowledge performance, the experimental condition gained a higher performance on domain relations that were shared by a participant collaborator dyad, compared to the control groups ($M_C = 2.1$; $M_E = 2.4$;$F(1,27) = 4.2$; $MSE = 0.14$; $p > .05$). This result constitutes evidence for the helpfulness of the KIA-Tool, because the participants were aware of which other collaborator had the same relation knowledge that they had. In addition, the analyses revealed higher performance by the experimental groups with regard to knowledge about information that is linked to concepts: In this context, the experimental groups gained higher values in knowledge regarding information that is only shared by the other collaborators, that is, the participant himself did not have this information (M_C = 2.6; M_E = 2.9; $F(1,27) = 4.17$; $MSE = 0.41$; $p = .05$). This result also provides evidence of the efficiency of the KIA-Tool: Considering information underlying a concept, participants in the experimental condition did remember more often items that both other collaborators had.

With regard to the problem solving tasks, the experimental groups tended to be more confident that they solved the two tasks correctly, compared to the control group (w.r.t. the pesticide problem: M_C = 3.8; M_E = 4.2; $F(1,27) = 3.38$; $MSE = 0.47$; $p = .077$; w.r.t. the fertilizer problem: M_C = 3.8; M_E = 4.2; $F(1,27) = 3.17$; $MSE = 0.57$; $p = .086$). This subjective estimation is partly mirrored in objective results, namely in the group answers given: Regarding the number of correct answers to the pesticide problem, the data did not show a significant difference between the conditions. However, with regard to the reasons given why they chose the correct pesticide the experimental condition was superior to the control condition (M_C = 0.2; M_E = 0.8; $F(1,27) = 3.36$; $MSE = 0.7$; $p < .1$). Contrarily, regarding the number of correct answers to the fertilizer problem, the experimental condition gained a higher performance compared to the control condition (Pearson-χ^2 (2) = 4.9; $p < .1$). But with regard to the reasons given why they chose the correct fertilizer there was no significant difference between the groups.

5 Conclusion

The presented study demonstrated that computer-supported collaborative problem-solving could be supported by a “knowledge and information awareness” tool (KIA-Tool) that made a group member aware of the knowledge and the corresponding underlying information of the other collaborators. In this study an experimental condition using this tool was compared to a control condition that worked without it. First results of the analysis showed that the participants of the experimental condition evaluated the use of the KIA-Tool as helpful. Comparing the two conditions it could be showed that the study was more stressful for the control condition, although the experimental condition had more difficulties in using the windows. Therefore, the benefit of using a KIA-Tool seems to be large enough to compensate the higher cognitive load caused by the need to use more windows. The analyses also showed that the experimental groups achieved higher performance in both knowledge regarding content information that was only shared by the other collaborators and knowledge regarding relation information that an individual and another collaborator had. In addition, the study demonstrated that using a KIA-Tool was helpful for problem solving performances. The results support hypotheses concerning the support of Web-based collaborative learning and problem solving by enhancing knowledge and information awareness. Further research activities will investigate in more detail the factors that are causative for the efficiency of the KIA-Tool.

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